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13. ABSTRACT ***(Maximum 200 Words)***

The Learning Resources Center (LRC), the hub of technology-based educational research at the University of California, San Diego (UCSD) School Of Medicine, has a strong track record for developing and distributing cutting-edge curricular resources. Under grants from DARPA (N00014-93-1-1278 and DAMD 17-94-j-4487) and ONR (N00014-97-1-0356), the LRC has spent five years developing "VisualizeR©", a virtual environment for the teaching and learning of complex three-dimensional (3D) structures in conjunction with large quantities of diverse pedagogic materials. "Anatomic VisualizeR©" combines 3D models (based on the National Library Of Medicine's Visible Human™ Dataset) with supporting 2D media (e.g., diagnostic imagery, surgical videos) to create compelling lessons in anatomy. The multimodal approach ("Virtual Reality - Multimedia Synthesis") is realized as a virtual dissection room where students can directly interact with 3D models and concurrently access supporting curricular materials. Anatomic VisualizeR learning modules (e.g., skull, ear, abdomen, and skeleton) have been piloted with high school students at Southwest High School (a health sciences magnet school in San Diego county), medical students at UCSD, and graduate nursing students at the Unformed Services University of the Health Sciences in Bethesda, Maryland.

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Jeanne M Hoffman 3/8/00

PI - Signature Date

Table of Contents

FINAL REPORT

MARCH, 2000

INTRODUCTION

The Learning Resources Center (LRC) of the University of California, San Diego (UCSD) School of Medicine, has been investigating the application of advanced digital technologies (including virtual reality, VR) for education and training, with the support of the Defense Advanced Research Projects Agency, DARPA, [DAMD 17-94-J-4487]. The overarching goal of these efforts has been to create an effective and efficient multimodal 3D environment where elements of virtual reality (VR), multimedia (MM), and communications technologies could be merged to form a unified learning paradigm. The initial phase of this *Virtual Reality-Multimedia Synthesis* (VR-MM Phase 1, a feasibility study also funded by DARPA [ONR N00014-93-1-1278]), was first described through a video mock-up at the "Medicine Meets VR 2" conference in January 1994 [1]. The following year, with the onset of the DARPA funded activities described herein, the developmental approach for VR-MM lessons was outlined. Particular emphasis was placed on addressing pedagogical issues [2, 3], since it was deemed the strength of the LRC's research unit.. While conceptual (open learning) or operational (task training) simulations were possible, the LRC chose the former, and by January 1996, the first working model of the VR-MM open learning environment was established [4, 5]. The challenge was to develop a 3D user interface paradigm that would support exploration and discovery-based learning while still providing the curricular structure necessary to ensure successful learning outcomes [6]. The current instructional design and the underlying multi-modal 3D software architecture (named *VisualizeR©*) were achieved by the beginning of 1997 [7] and are described below.

BODY

Selection of Subject Domain

The scientific domain selected for UCSD's first *VisualizeR©* lessons was human anatomy since it represented one context in which a VR-based strategy appeared both achievable and apropos. Once developed, virtual anatomy lessons would be appropriate for use either as adjuncts to or as replacements for the current practices in anatomy education -- a combination of lectures and laboratory dissections. While still considered the "gold standard" against which alternatives are judged, standard educational methods can fall short of instilling the requisite 3D conceptualization, retention, and application of anatomic knowledge to clinical problem solving [8, 9]. The pedagogical challenges are further complicated by reduced hours available to anatomy education [10, 11] and a growing need to find alternatives for cadaver and animal specimens resulting from scarcity, costs, aesthetics, and environmental concerns [12]. Strategies such as plastic specimens, videos, and multimedia computer programs have utility, but do not seem to provide fully satisfactory dissection alternatives [8].

Instructional Design and User Interface: Issues and Solutions

Efforts to develop *Anatomic VisualizeR* began with an assessment of faculty and student needs for anatomy training at UCSD and a consideration of current best practices for anatomy education in a wide variety of contexts [4,7]. The resulting information was neither new nor surprising to individuals who have spent significant time teaching human anatomy to medical students. However, organizing these findings and articulating them as educational and developmental goals was an important first step in the development process. It also established that once developed, *Anatomic VisualizeR*-based anatomy lessons could be used either as adjuncts to or as replacements for the current practices in anatomy education.

The design of *Anatomic VisualizeR* evolved considerably during the initial years of its development, and a variety of human-computer interfaces were investigated. A review of the UCSD videotape #1 (referenced in appendix) demonstrates this evolution. In its current iteration, *Anatomic VisualizeR* [Fig. 1] provides a virtual dissecting room in which students and faculty can directly interact with 3D models (anatomic, schematic, etc.) and concurrently access supporting curricular materials (text, images, sound, video, etc.). Instructional activities, organized into learning modules, can be selected from a collection of previously developed learning modules or can be specially developed using the associated lesson authoring environment. Modules can be created for individual instruction, for presentation in large group settings, and for other curricular contexts.

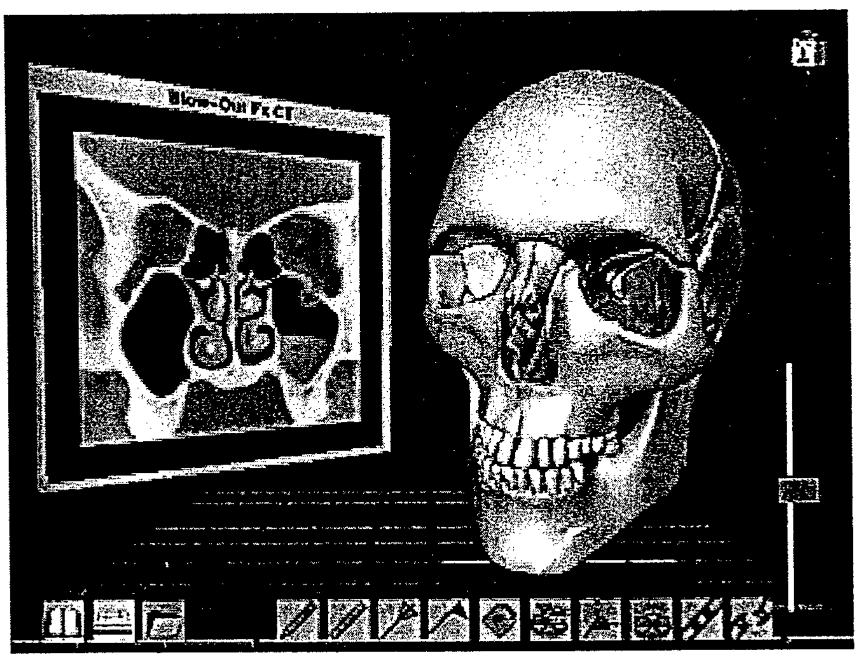

Fig 1. A scene from an *Anatomic VisualizeR* learning module, Clinical Anatomy of the Skull. This portion of the lesson provides students with access to both the 3D models of the skull and diagnostic images demonstrating the effect of trauma to the head. The small object in the upper right corner of the room, is a 3D reference tool which indicates the anatomic position of the models. The menubars at the bottom of the room provide tools for interacting with the anatomic models (right) and environmental controls (left).

The *Anatomic VisualizeR* paradigm has been created to encourage exploration, discovery, and active learning by enabling students to creatively construct individualized and self-paced experiments. The learning modules are also designed to help students create a symbolic framework for anatomical knowledge, as well as to establish a context in which to integrate clinical skills and reasoning. The balance between student-centered, discovery-based learning and curricular structure was achieved though the combined use of a Study Guide and Application Toolbars.

The virtual Study Guide [Fig. 2] provides a mechanism for directed mentoring and can be used to organize key concepts, load and unload lesson resources, suggest student exercises, and provide selectable links to contextually relevant resources from multiple domains of medical science

(histology, pathology, radiology, etc.). Toolbar options for anatomic models confer on the student the ability to: link and unlink anatomic organs, change organ transparency or size, dynamically create cross sectional views using a clipping plane, measure sizes and distances with an virtual ruler, label structures with a flag marker, and draw lines and simple objects using a 3D drawing tool. Anatomic orientation of displayed organs is indicated regardless of their placement, orientation, or magnification within the virtual environment. In addition to anatomy-specific user tools, other Toolbar options provide certain environmental controls. Options to turn on and off a 3D perspective grid, to turn on and off the Study Guide, and to search for and load additional resources have proven extremely useful.

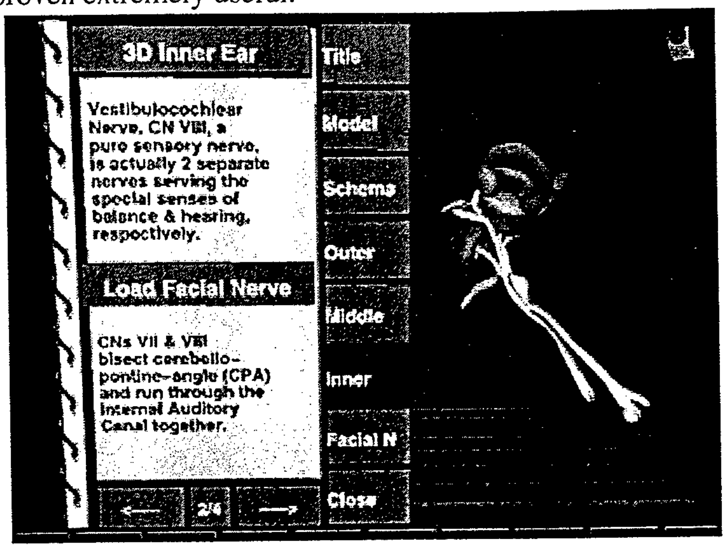

Fig 2. A scene from an *Anatomic Visualizer* learning module, Anatomy of the Ear, highlighting the Study Guide portion of the application. The tabs on the right side of the Study Guide provide ready-access to each segment of the lesson. The forward and back arrows and a numeric indicator provide the navigation within tab sections. Study Guide pages such as the one shown, can include descriptive text and links to additional resources.

The Study Guide is intended to be uniquely customized by faculty authors for each anatomy lesson module. The Lesson Editor developed for *Anatomic VisualizeR*, while still rudimentary, provides a simple graphical user interface that can be used to "storyboard" and then try out lessons [Figure 3]. Faculty can specify the sequence of Study Guide pages or tabbed sections, and each page can specify what lesson resources are to be loaded where. Page headers and text can be entered, and buttons with anchors for either accessing "Clinical Correlates" or changing scene appearance can be inserted. Lesson Editor output is an ASCII file which can also be further modified using any text editor.

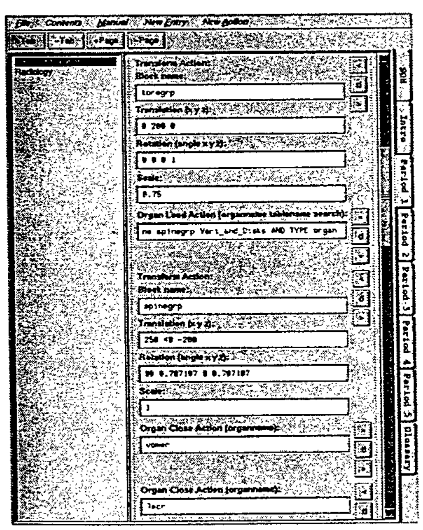

Figure 3. Lesson Editor. Elements on the "Thoracic Skeleton" page in tabbed section "Period 1", showing placement, scaling, loading and unloading of anatomic models. Using the Lesson Editor, authors are able to 1) create new, edit (cut, copy, and paste), and arrange (move up and move down) tabs; 2) create, edit, and arrange study guide pages and page content; and 3) insert section headers, text, images, or links within study guide pages. The scene and behavior commands change the contents or appearance of the VR scene. Scene contents may include 3D models, a variety of available lesson resources including specific tools or 2D multimedia. Any scene content item can be arranged and placed within the scene.

A broad range of virtual exploratory tools and options are available which enable users to investigate structures in ways not possible in the real world [Fig 4]. Students are able to repeatedly "dissect" structures and regions, or to reconstruct any area from its component parts. The options available to users include: link/ unlink models, change opacity or size, dynamically create cross-sectional views using a clipping plane, measure sizes and distances with a virtual ruler, mark structures with a flag, identify structures using a probe, and draw lines and simple objects using a SpaceDraw tool. Anatomic orientation can be maintained regardless of view or magnification, and anatomic position can be reestablished through other menubar options. Moreover, within any lesson and at any time, a student may choose to access additional information resources (e.g., correlative histology or pathology images, surgical videos, diagnostic studies) using Anatomic VisualizeR's search tool.

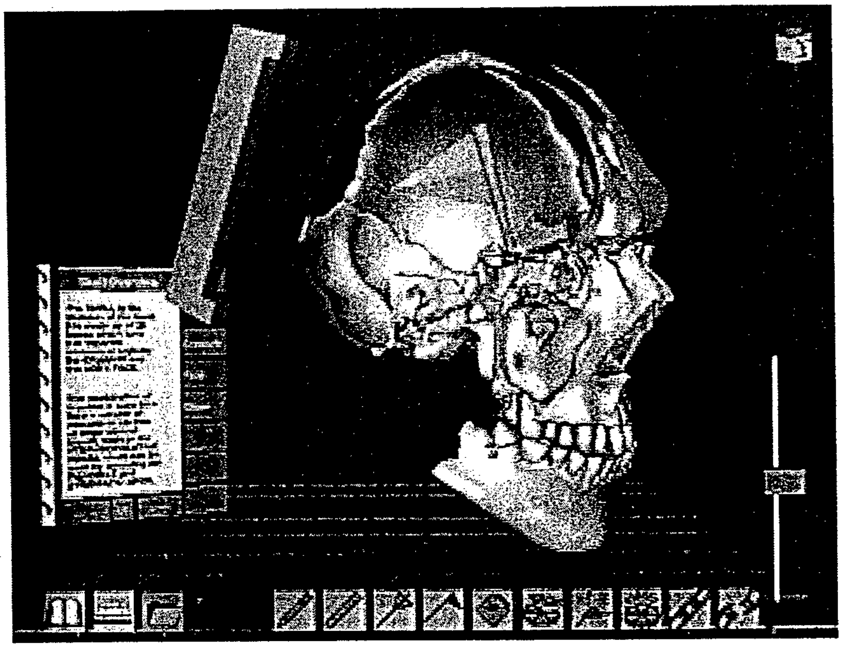

Fig 4. A scene from an *Anatomic Visualizer* learning module, Clinical Anatomy of the Skull, includes the Study Guide and array of virtual tools. It depicts the use of the clipping plane to create dynamic cross sections of the skull. Also seen is the flag took, marking a structure in the skull's interior. The menubar in the lower right side of the room includes the following tools (R->L): scaling, unlink, link, highlight, orient part, orient whole, clipping plane, flag, probe, ruler, and SpaceDraw. The smaller menubar on the lower left side includes (R->L): search, grid on/off, Study Guide on/off.

3D Models

Initially, 3D models were obtained from New Leaf Systems (a.k.a Talisman) in San Carlos, CA. However these models presented a number of insurmountable problems: 1) they were sequentially organized and would not support exploratory learning; 2) they were cartoon-like and not anatomically correct; 3) their level of detail was not sufficient to be useful for training at any level of medical education; and 4) the anatomically-based portions of the model represented only a fraction of the VR world, with considerable emphasis placed on the environment (operating table, room, lights, etc). Attempts to isolate the models from the environment and to correct anatomic deficiencies proved unsuccessful, and the subcontracting relationship was terminated..

After reviewing a variety of options, models derived from the National Library of Medicine's Visible Human Project™ dataset [14], and supplied by Visible Productions, Inc., were selected. Making these anatomic models fulfill both technical and educational requirements was challenging, but feasible. Although these models were of very high quality, major implementation issues quickly emerged. First, a finite number of polygons could be moved and manipulated at one time, depending on technical limits such as the graphics capability of the machine and whether the display is monoscopic or stereoscopic. This impacted the size and number of organs that could be concurrently used in any one lesson scene. Efforts to globally "decimate" the number of polygons

frequently reduced the level of structural fidelity below that required to meet instructional needs and only served to exacerbate faculty concerns regarding the teaching value of certain idiosyncratic anatomic elements. After careful consideration of the problem and potential solutions, an alternative method for modification of the anatomic models was devised: a medical illustrator was tasked to use VPSCULPT© [15] to optimize each anatomic organ model. Model structures were sculpted - facets were selectively added and removed - selected areas were decimated, and normals were changed where necessary. An example of one particularly difficult structure before and after processing is illustrated in Figure 5.

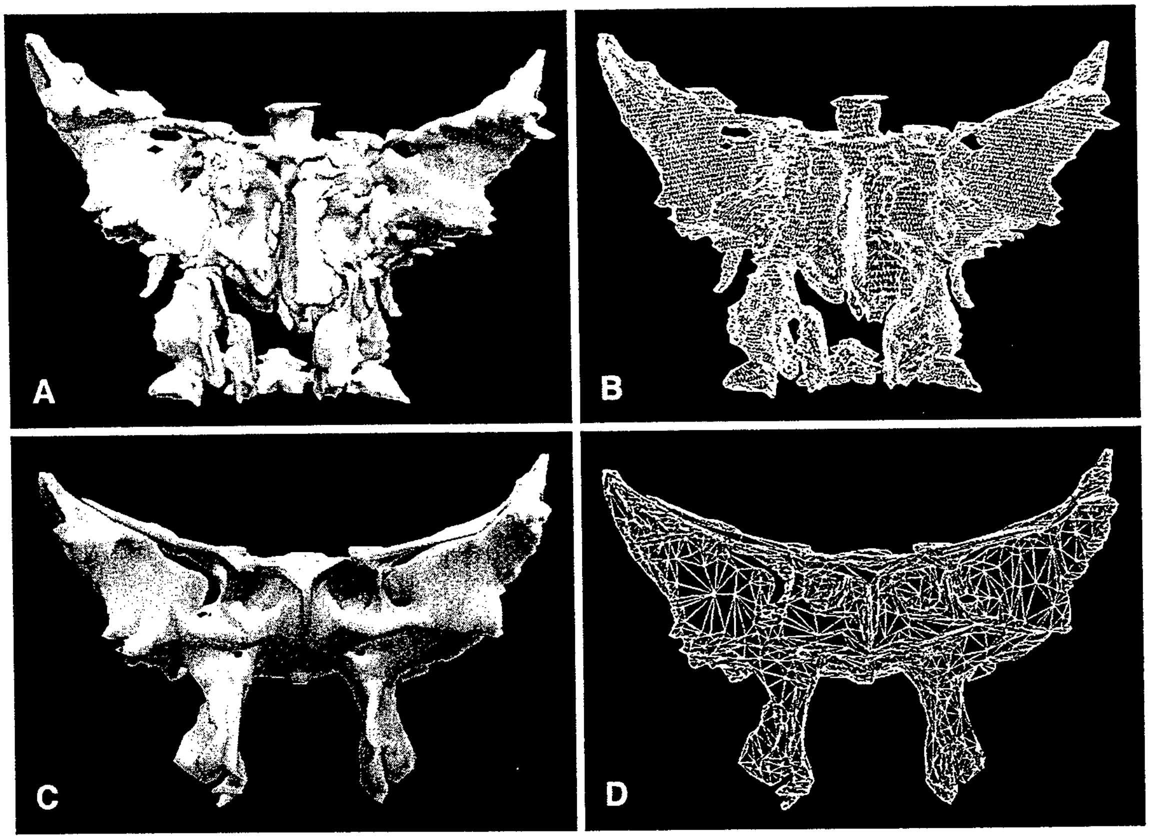

Figure 5. Anatomic Model Optimization. Model of the sphenoid bone of the skull as received (A) and after sculpting to make the structure anatomically accurate (C). Corresponding wireframe representations visually show polygons before (B) and after decimation (D).

Virtual Environment Choices and Evaluation

Anatomic VisualizeR's architecture supports multiple types of visual display (monoscopic CRT, stereoscopic CRT, and head mounted display (HMD)) and input options (gloves with motion trackers, 3D trackball, and mouse). With so many supported choices, parallel efforts have consequently been directed at characterizing the effects of these option choices on student perception and performance. The first of these studies, sponsored by the Office of Naval Research [ONR, N00014-97-1-0356], examined the impact of VE system design manipulations on the perception of 3D space as indexed by the performance of a simple perceptual-motor task.[16]. Medical student subjects were asked to use gloves and trackers to select a geometric object appearing randomly at different depths on the display. Task performance was then compared across

four different VR device configurations and using four different user interface layouts. Preliminary analysis of these data suggest that all users successfully accommodated changes in hardware viewing configuration as well as software depth cures such that performance of the simple task was not highly influenced by the characteristics of the VE. Moreover, simulator sickness symptoms, as measured by the Kennedy "SSQ" simulator sickness questionnaire, were absent in users of the VisualizeR system in this protocol. Further studies with larger sample sizes will be required to examine more complex and realistic tasks wherein learning outcomes will also be considered.

Anatomic VisualizeR in the Classroom (UCSD Video #2)

- *K-12 applications*

VR-MM based anatomy lessons have been developed for and implemented in a wide variety of curricular contexts. The first classroom application of *Anatomic VisualizeR* has occurred after the creation of a lesson entitled "VR Laboratory for Advanced High School Anatomy" [Fig. 6]. This high school level virtual anatomy lesson has been piloted even while the 3D models and another lesson were still being optimized for the medical school anatomy curriculum. The lesson modules for the high school students were authored, in large part, by their teacher working in the LRC on a summer faculty development fellowship. The process began with a brief orientation to the *Anatomic VisualizeR* environment and an introduction to the Lesson Editor tool. The virtual lessons were created as an adjunct to the lecture and independent study components of her course. The exercises were divided into an introduction and 5 lesson modules, and a problem-based approach was used for most activities. A wide range of anatomic topics and activities were included. For example, students were given an opportunity to measure the length of the virtual spinal column, construct the thoracic skeleton from component parts, identify a fracture line on an x-ray and then label the same site on the skeletal model, deconstruct the skull and locate specific bones, and visualize structures hidden deep in the abdominal cavity by making exterior structures transparent, removing extraneous structures, or by using the clipping plane tool. This pilot project, undertaken in 1998-1999, brought more than 30 senior high school students to the LRC for two half-day sessions [Fig. 7]. Pre- and post-tests developed by their teacher, as well as written student comments on to the virtual learning experience, provided important usability data that helped refine *VisualizeR's* user interface and interaction paradigms.

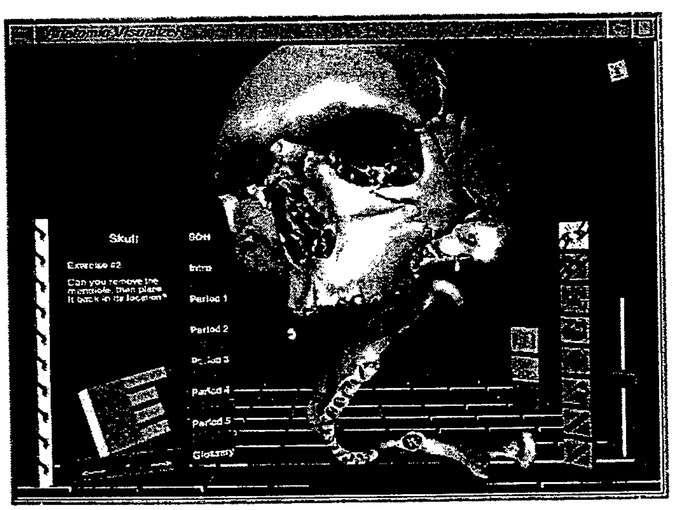

Figure 6. A page from the High School Advanced Anatomy Lesson. Exercise instructions on the Study Guide page have directed the student to remove the mandible from the skull and then place it back in its location. An avatar of the student's hand appears with a pointer to aid in precise selection. Environment toolbar options appear behind (and to the left of) organ toolbar option and scale bar. Indication of anatomic position appears in the upper right hand corner.

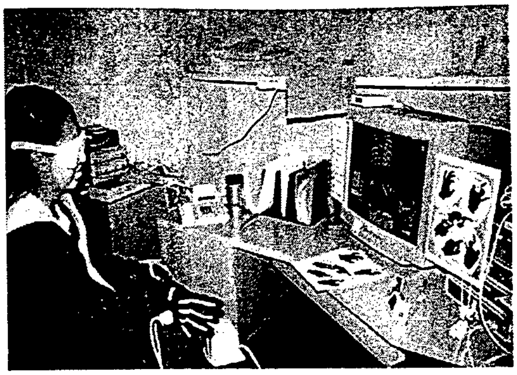

Figure 7. A High School using *Anatomic VisualizeR* as part of her Advanced Anatomy laboratory experience. This student is viewing the VE in stereoscopic mode using shutterglasses. She is interacting with the lesson using switch gloves and a simple gestural syntax.

At UCSD, *Anatomic VisualizeR* has been a part of the School of Medicine's Human Anatomy course since 1998 for the teaching of the sphenoid bone and the autonomic cranial nerves [Fig 8]. In 1999, a lecture on the anatomy of the human ear was also delivered to the UCSD medical students using this application. On each of these occasions, the corresponding *Anatomic VisualizeR*-based learning module was made available for individual and small group sessions on a voluntary basis and was utilized by 40-50% of the UCSD class.

Figure 8. Mark Whitehead, Ph.D., Director of UCSD's Human Anatomy course using *Anatomic VisualizeR* to support the teaching of complex 3D materials. For the auditorium setting, the application is projected in monoscopic mode and one of the LRC staff manipulates the 3D models according to direction provided by the faculty.

Anatomic VisualizeR made its curricular debut outside UCSD in the Fall of 1999 when it was used for the teaching of two graduate-level nursing anatomy lectures at the Uniformed Services University of the Health Sciences (USUHS), in Bethesda Maryland. USUHS is currently running the only alpha version of *VisualizeR* outside of the LRC and will be jointly developing other VR-based anatomy lessons over the next year. Both the USUHS and high school experiences have reinforced the necessity of porting the *VisualizeR* application to a platform (e.g., Linux or WindowsNT) that will make distribution to a wider student audience more feasible.

Future Plans

The overarching goal is for *Anatomic VisualizeR* to emerge from the research laboratory and enter the classroom. Lesson development is one of our highest priority activities. Significant efforts will also be expended on developing low cost versions of the program to ensure that the *VisualizeR* environment can be used in the widest possible range of venues. As an ongoing part of all activities, we will continue to extend our understanding of human learning in VEs and to characterize the educational outcomes and cost-benefit of learning with these new tools. Moreover, commercial avenues through which to market *VisualizeR* will continue to be sought.

Key Research Accomplishments

VR-MM architecture formalized

- The name *"VisualizeR"* was selected to describe the Virtual Reality-Multimedia (VR-MM) software architecture developed by the University of California, San Diego (UCSD) School of Medicine's Learning Resources Center (LRC).
- *VisualizeR* is a virtual learning environment suitable for the teaching and learning of any subject for which the visualization of spatial relationships and the juxtaposition of 3D objects and multimedia is critical to understanding.
- *VisualizeR* includes the following features:
  - 3D workspace
  - Current access and interaction with 3D polygonal models, 2D digital imagery, video clips, sounds, organized text
  - The ability to manipulate any loaded content resource and choose to search for and load additional resources.
  - Learning module scripts and content resources which may reside on network servers, and be accessed and loaded via database query
  - A *Study Guide* for descriptive text, navigation, and links to contextually related resources.
- *VisualizeR* is a flexible architecture which can be customized without the need for recompilation
  - Users can specify preferences for tool placement, background color, device choice, etc
  - Teachers can develop lessons in which they control the elements, placement, and interaction within every virtual scene
  - Choice of interaction device and type of display is made at run-time
- *VisualizeR* is an extensible architecture
  - Modules to support other resource display formats and/or interaction tools can be added (In many cases implemented as dynamically shareable objects loaded only as needed)
  - New device drivers may also be implemented and included.

Authoring environment devised

- Provides a simple graphical user interface for faculty to develop/edit learning modules
  - Creates new, edits (cut, copy, and paste), and arranges (moves up and moves down) tabs
  - Creates, edits, and arranges study guide pages and page content
  - Inserts section headers, text, images, or links within study guide pages
  - Furnishes scene and behavior commands to change the contents or appearance of the VR scene
- Establishes ASCII file which can also be further modified using any text editor.

VR-based learning environment, "Anatomic VisualizeR", established using the VisualizeR architecture

- *Anatomic VisualizeR* provides a virtual dissection room where students can directly interact with 3D polygonal models based on the National Library of Medicine's Visible Human™ dataset
- *Anatomic VisualizeR* enables concurrent access to supporting 2D media (e.g., diagnostic imagery, surgical videos, etc.) to create compelling lessons in human anatomy.
- *Anatomic VisualizeR* includes exploratory tools:
  - *3D reference plane*: indicates anatomic orientation of displayed organs regardless of placement, orientation, or magnification
  - *Scale*: changes 3D model size from 20-200%
  - *Link & unlink:* enables virtual dissection of reconstruction from component parts
  - *Highlight & change opacity*: provides alternative visualization options
  - *Cut-plane viewer*: enables anatomic models (singly or in groups) to be dynamically visualized in cross section and with cuts made in any 3D plane.
  - *3D space drawing tool:* allows user to draw/trace using a ribbon of color which can remain in the world as an annotating element.
  - *Flag marking tool:* permits sub-structures to be marked for testing or comment.
  - *3D ruler*: allows user to measure anatomic structures
  - *Probe tool:* indicates all models (visible and hidden) that it intersects
  - *Reorient*: establishes anatomic position of one or more models
  - *Search*: identifies and loads additional user-specified resources

Methods and approaches to 3D modeling established.

- For remodeling 3D objects to ensure accuracy and optimize application performance
  - Requires reductions in polygon count of 70%-90%
  - Includes careful editing of facets and adjusting of polygonal patterns
- Methods established for creating new anatomic structures and 3D conceptual schematics.

Anatomic VisualizeR lessons developed

- Abdominal anatomy & Hepatobiliary anatomy (completed 1997-98)
  - Primary authors: Hoffman, Vu, Whitehead, et. al.
  - Target audience: medical students
  - Instructional context: prototypes used for demonstrations, formative evaluations, etc.

- *Advanced anatomy laboratory* (completed 9/98)
  - Target audience: high school students
  - Primary authors: Luera, Hoffman, et. al.
  - Instructional context: used individually in LRC during half-day fields trips from high school to UCSD.
- *Sphenoid bone* (completed 11/98, revised 11/99)
  - Primary authors: Whitehead, Hoffman, et. al.
  - Target audience: medical students
  - Instructional context: Used in lecture (UCSD) and optional small group sessions (LRC)
- *Clinical anatomy of the skull* (completed 10/99)
  - Primary authors: Bustos, Hoffman, et. al.
  - Target audience: graduate nursing students
  - Instructional context: Used in lecture (USUHS)
- *Clinical Anatomy of the Ear* (completed 10/99)
  - Primary authors: Bustos, Hoffman, et. al.
  - Target audience: graduate nursing students
  - Instructional context: Used in lecture (USUHS)
- *Gross Anatomy of the Ear* (completed 11/99)
  - Primary authors: Clay, Hoffman, et. al.
  - Target audience: medical students
  - Instructional context: Used in lecture (UCSD) and optional small group sessions (LRC)

Memorandum Of Understanding established between the regents of the University Of California San Diego Campus and the Uniformed Services University Of The Health Sciences

- May 1999
  - To collaborate in the development of two virtual reality neuroscience lessons using the Anatomic VisualizeR
  - To present the Anatomic VisualizeR lessons at USUHS in its Graduate School of Nursing in October, 1999.
- September 1999
  - Extends the effective date of the MOU until 30 September 2000.
  - Provides for the loan of one complete Anatomic VisualizeR set-up (hardware and software)
  - Establishes USUHS as an alpha site for Anatomic VisualizeR lesson development
  - Sets the stage for a larger collaboration between UCSD and USUHS that eventually will be effected by a formal partnership agreement.

REPORTABLE OUTCOMES

Manuscripts

- Hoffman, H.: *Virtual Reality and the Medical Curriculum: Integrating Extant and Emerging technologies.* Proceeding, Medicine Meets Virtual Reality II: Interactive Technology and Heathcare, UCSD, 1994.
- Hoffman, H.: *Virtual Reality Meets Medical Education*, Interactive Technologies and the New Paradigm for Healthcare , K. Morgan et al, (ed), IOS Press, 130-136, 1995.
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- Hoffman, H.:*Virtual Reality & Medical Education: Integrating Extant and Emerging Technologies*, Electronic Proceedings of Ausi'VR 95, Melbourne Australia, 1995
- Vu, D. and Hoffman, H.: *Anatomic VisualizeR: a Virtual Reality-based Learning Application,* American Association of Clinical Anatomists abstracts, 1997
- Hoffman, H.: *Implementing Anatomic VisualizeR Learning Modules in Anatomy Education,* Medicine Meets Virtual Reality Abstracts, 2000.

Presentations

- *Virtual Reality & the Medical Curriculum* @ Ausi VR'94, Melbourne Australia, 10/94.
- *Medical Education Meets Virtual Reality* @ Medicine Meets Virtual Reality III, San Diego CA, 1/95.
- *Teaching & Technology, the Future of Medical Education* @ AAMC Council of Teaching Hospitals, Seattle WA, 5/95.
- *Virtual Reality Meets Medical Education* @ USC Medical Informatics Seminar, Los Angeles CA, 6/95.
- *A Virtual-Reality Multimedia System for Anatomy Training* @ Medicine Meets Virtual Reality IV, San Diego CA, 1/96.
- *Teaching and Technology: A Vision for Medical Education* @ AAMC Group on Business Affairs, Charleston SC, 3/96.
- *Developing a VR Multimedia System for Anatomy Training* @ FASEB'96 Symposium, Washington DC, 4/96.
- *Teaching and Technology: A vision for Medical Education* @ Medical Library Association Collections Group Sponsored Symposium, Kansas City MO, 6/96.
- Extending Multimedia Training into 3D Space @ Medicine 2001, Montreal Quebec, Canada, 6/96.
- *Virtual Anatomy from the Visible Man: Creating Tools for Medical Education* @ Visible Human Conference, National Library of Medicine, Bethesda MD, 10/96.
- *Computers and Communications Technology in Graduate Medical Education* @ Group on Resident Affairs, AAMC National Meeting, San Francisco, CA, 11/96.
- *A 3D Architecture for the Development of Virtual Anatomy Lessons* @ Medicine Meets VR5, San Diego CA, 1/97.
- *Anatomic VisualizeR -- A Virtual Reality-based Application for the Study of Human Anatomy* @ All University Conference on Teaching and Learning Technologies, Los Angeles, 3/97.
- *Teaching, Learning, & Information Technology -- An American Perspective* @ Towards The Smart Community, Revolution'97, Adelaide Australia, 9/97.
- *Anatomic VisualizeR -Teaching & Learning Anatomy with Virtual Reality* @ IEEE Workshop Chicago, 10/97.
- *Virtual Reality - Next-Generation Learning Environments* @ University of San Diego, University of the Third Age, 1998 Winter session, course faculty, 1/98.
- *Assessing a VR-Based Learning Environment for anatomy Education* @ Medicine Meets VR6 Conference, 1/98.
- *VR and the Medical Curriculum* @ Tamkin Medical Informatics Symp., UC Irvine, 2/98.
- *Teaching & Learning with VR* @ Rice University Center for Technology in Teaching and Learning, 1997-98 Speaker Series, 2/98.

- *Teaching & Learning with Virtual Reality* @ , International Telemedical Information Society, Amsterdam, 4/98.
- *UCSD's Anatomic VisualizeR - A VR-based environment for education* @ UCSD Foundation Board of Trustees Meeting, 9/98.
- *Creating VR-based Anatomy Lessons from the Visible Human Data* @ 4th International Congress on New Technology in Surgery, Munich Germany, 12/98.
- *UCSD's VisualizeR: VR for Science Education* @ UCSD Connect, 12/98.
- *Anatomic VisualizeR: UCSD's Virtual Environment for Anatomy Education* @ SAIC National Program Managers Meetings Week, R&D Session "Human Computer Communications", 1/99.
- *VR-Multimedia Synthesis/ VR and Medical Education* @ NASA/DARPA Project Investigator Review, 1/99.
- *Anatomic VisualizeR: Realizing the Vision of a VR-based Learning Environment* @ Medicine Meets VR7, 1/99.
- *Virtual Reality for Medical Education* @ NYU School of Medicine, 2/99.
- *Information Technology & Medical Education* @ SUNY:Syracuse Health Sciences, 3/99.
- *VisualizeR* @ UC Digital Media Innovation Program Workshop, UCSB, 5/99.
- *Anatomic VisualizeR* @ National Assoc. of Minority Medical Educators, San Diego, 5/99.
- *Experience with UCSD's "Anatomic VisualizeR"- A VR-based Learning Environment for Human Anatomy* @ Stanford & NASA workshop on Future of Biocomputation, 6/99.
- *Anatomic VisualizeR-based lessons on ear & skull (with O. Bustos MD)*@ USUHS, 10/99.
- *Implementing Anatomic VisualizeR Learning Modules in Anatomy Education* @ Medicine Meets VR8, 1/00
- *La Realidad Virtual en el Entrenamiento de Cirujanos Y Enfermeras (Virtual Reality Training fro Surgeons and Nurses)* @Congreso Internacionale de Cirugia Endoscopica, Tiajuana, 2/00

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Personnel receiving pay from the research effort

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Conclusions

UCSD School of Medicine has been actively exploring the use of VR to enrich anatomy education, particularly through the combination of VR and traditional curricular resources. As the period of DARPA-funded research and development comes to a close, UCSD's virtual learning environment for human anatomy has been realized. The current research activities have culminated in several pilot projects, wherein high school and medical school students have had an opportunity to participate in a brief lesson using Anatomic VisualizeR©. Data from these studies, together with a variety of anecdotal reports, strongly suggest that learning using Anatomic VisualizeR© is highly beneficial. However, a more complete curriculum must be developed, implemented, and assessed within diverse classroom contexts in order to verify the effectiveness of this VR-based instructional approach.

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APPENDIX

Reprints of selected articles

A1. Hoffman, 1995

A2. Hoffman, 1996a

A3. Hoffman, 1996b

A4. Hoffman, 1997

A5. Hoffman, 1998a

A6. Hoffman, 1998b

A7. Hoffman, 1999

Video documentation

A8. UCSD Videotape #1: Anatomic VisualizeR Project Reel, Helene Hoffman, Ph.D., demonstrating evolution of Anatomic VisualizeR interface and functionality (Run time 35 minutes).

A9. UCSD Videotape #2: Anatomic VisualizeR 2000, Helene Hoffman, Ph.D., demonstrating curricular application of the program (Run time 6.45 mintues).

Curriculum Vitae

A10. Helene Miller Hoffman, Ph.D.,

A1

Interactive Technology and the New Paradigm for Healthcare
K. Morgan, R. M. Satava, H. B. Sieburg, R. Mattheus, and J. P. Christensen (Eds.)
IOS Press and Ohmsha, 1995

Chapter 22

Virtual Reality Meets Medical Education

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Abstract. The University of California at San Diego (UCSD), School of Medicine is undertaking a multi-year project to create an educational computing environment which integrates elements of Virtual Reality, Multimedia, and communications technologies. The goal of this endeavor, named the Virtual Reality-Multimedia Synthesis project, is to create next-generation educational tools which extend the flexibility and effectiveness of medical teaching, promote the development of lifelong learning, and gain acceptance within the mainstream academic community. The initial phase, a feasibility study which is now complete, resulted in the production of a mock-up and video which communicated this vision and enabled feedback from potential end-users. Phase 2, now underway, involves the development and evaluation of a prototype system. Over the next three to four years, a working version is expected to be available for expanded testing in venues beyond UCSD.

1. Introduction

Virtual Reality (VR) has enormous educational potential and will likely become the foundation of next-generation simulations used by medical professionals at all levels [1]. VR-based visualization and training environments could provide beginning students with engaging and immersive 3-D views of anatomic structures and spatial relationships. Surgical residents could learn new techniques or rehearse procedures before attempting the actual operations. An unlimited pool of virtual patients, combined with existing curricular opportunities, would increase the depth and breadth of clinical exposure, ensure the uniformity of training experiences, enhance skill acquisition, and ultimately improve the quality of health care delivery.

VR could also be used to develop a unifying interface for accessing supporting multimedia and telecommunications resources. In education this is important because no single technology can provide a complete curriculum for our students. The wealth of extant medical teaching materials including books, atlases, image banks, databases, animations, and documentary videos should not be discarded as we move towards adopting more advanced systems. Rather, these multimedia resources should be made available within VR to add depth and clarity to the learning process as well as support and enrich the virtual experience.

2. Virtual Reality-Multimedia Synthesis Project

At the University of California San Diego (UCSD), a VR research lab has been established within the School of Medicine's Learning Resources Center (LRC) to experiment with VR-systems in combination with multimedia-based educational resources. This project, which we have named Virtual Reality-Multimedia Synthesis (VRMMS), has three broad objectives. The first and most general goal is to support medical education at all levels (including medical students, residents, and faculty), and to promote educational interests and academic standards within the general VR community. Our second goal is to develop next-generation learning environments by hybridizing diverse educational technologies (such as VR and MM) and incorporating the communications resources increasingly central to medical education and practice. Our third goal is to establish methodologies and implement educational outcomes analyses for documenting the effectiveness of these advanced systems.

UCSD's VRMMS project is a multi-year endeavor with three developmental phases, which unlike other projects developed at the LRC [2], is not targeted for immediate curricular implementation.

2.1. VRMMS Phase 1

The first phase of development, now complete, was presented at the 1994 Medicine Meets Virtual Reality Conference [3]. Phase 1 involved establishing the core development team, defining the educational goals, identifying instructional design and interface issues, building a collective vision, creating the system mock-up, and producing a demonstration video.

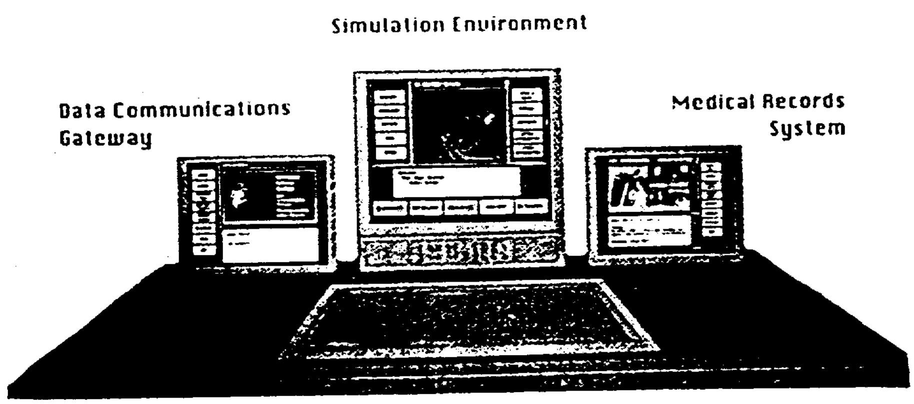

Figure 1. *A graphic representation of the VRMMS Phase 1 mock-up. This modular design facilitates staged development and implementation of specific components. Navigation within or between modules will use a combination of voice and touch-screen controls.*

Our Phase 1 design (Figure 1) employed a linked 3-computer array, representing functionalities we deemed important. The Data Communications Gateway (Figure 2) would provide access to local and remote electronic resources via UCSD's Metropolitan Wide Area Network and the Internet. The Electronic Medical Record System (Figure 3) would link students to the hospital information system for data on real and simulated patients. The Simulation Environment (Figure 4) would serve as the controlling interface and VR-based surgical simulator. This modular design was selected because it would facilitate staged development and implementation.

At the end of the design phase, we built a mock-up and produced a short demonstration video [7]. The system depicted, while not real (it was created using 3-D animations and multimedia tools), was realistic, and has been very successful in communicating our vision and getting feedback from potential end-users.

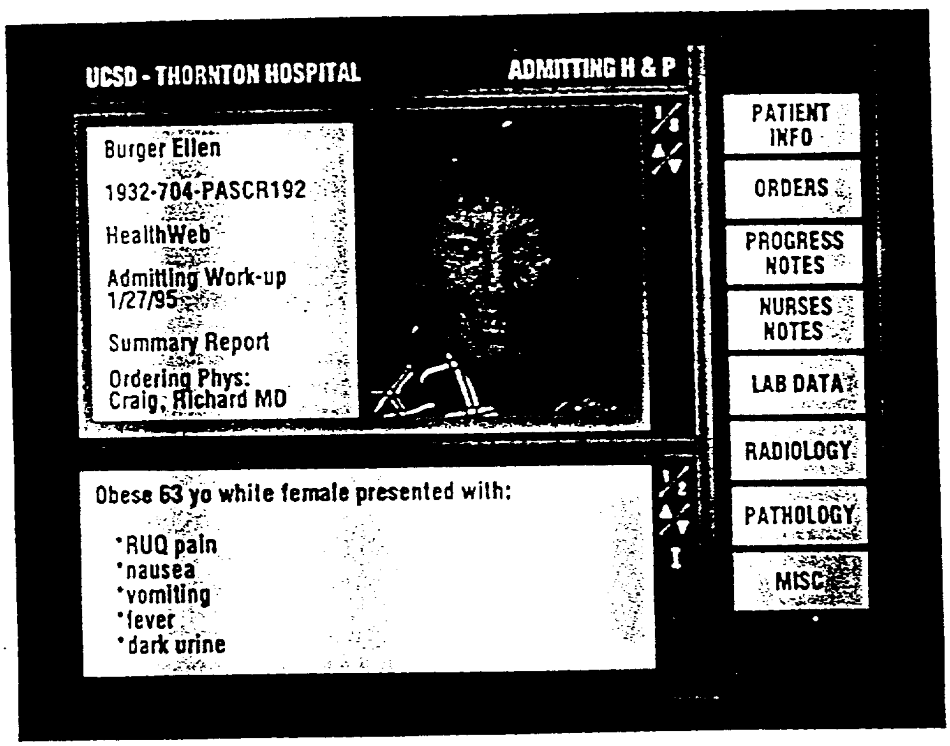

Figure 3. Linked to the surgical scenario, the right screen provides access to a depiction of an electronic medical record system, enabling users to review the pertinent history (shown here), presenting symptoms, and results of previous diagnostic studies for the patient being simulated. Additional information generated during the simulated procedure would be automatically posted to the patient's record as appropriate.

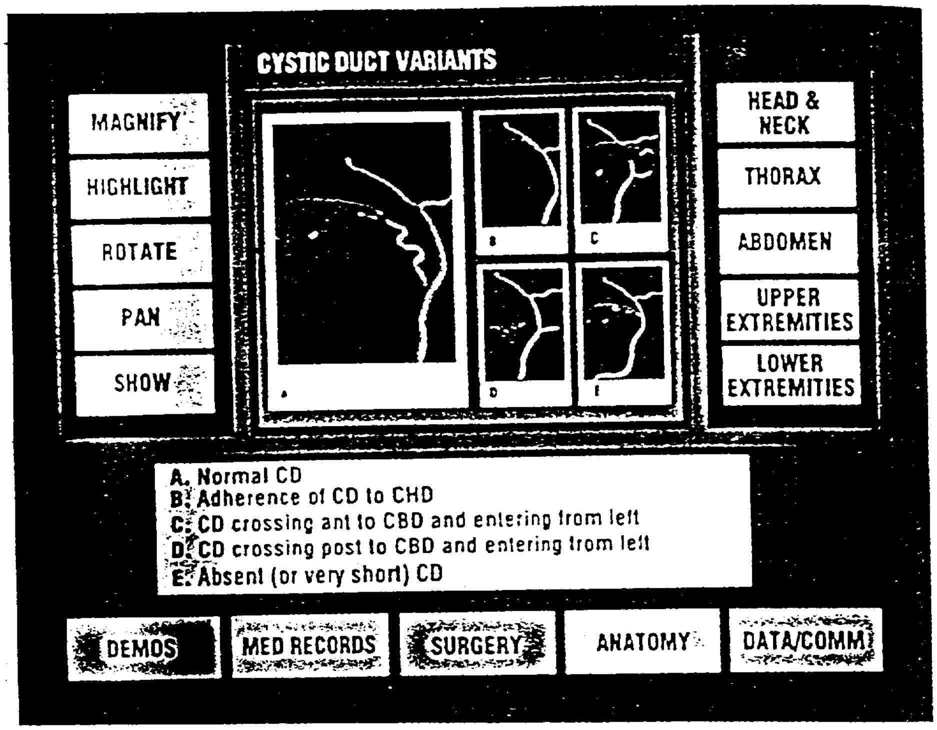

Figure 4. The center screen provides access to the "virtual" patient, created for this mock-up using a combination of 3-D animation, video, and still images. These early multimedia simulations, as well as more advanced VR-based cases, will be useful for teaching normal and abnormal anatomy (shown here) and for rehearsing surgical procedures.

2.2. VRMMS Phase 2

Translating our vision into a working prototype began in mid-1994. Having studied the mock-up for nearly a year, we started Phase 2 with a much clearer understanding of the issues and obstacles facing us. Our first challenges involve the core technologies and methodologies including the VR-multimedia engine and the user interface.

In parallel to these engineering efforts, we are creating multiple test lessons which combine VR and multimedia. Because establishing a new paradigm for medical education is a difficult process, care was given to the selection of a target content area for these lessons. Demonstrated educational need, availability of resources, feasibility of a technology-based solution, cost, and appropriateness of resource allocation were among the criteria considered.

In the end, we have decided on three target lessons, each having different learning objectives specially aimed at users with varying skills levels and needs, but all based on a single 3-D model of the abdominal cavity. One plan targets medical students studying

anatomy. The second is intended for physicians making diagnoses of gall bladder disease. The third is meant for surgeons and simulates laparoscopic abdominal surgery. The model that provides the "virtual" core of our lessons comes from New Leaf System (now Talisman Dynamics Inc), a well-known developer of VR environments [8, 9].

Building VR-MM lessons is only part of our Phase 2 plan. We are also extremely interested in understanding how technology impacts the educational process and examining the merits of VR-based teaching systems in general, and our prototype system specifically. Because the requirements for learning systems may vary with the task and skill level of the user, the role of simulation variables and interface design on skill acquisition and knowledge transfer will also be explored [10-13]. Specific items to be considered include: fidelity, latency, visual display devices, gesture tracking, and the methodology used to present 2-D multimedia data within a 3-D simulated environment.

In addition, a cost-benefit analysis of implementing these technologies will also be undertaken for each type of end-user application. This will be particularly important in helping ensure that these systems are accepted within the academic community and affordable to the educational institutions using them.

Towards the end of Phase 2, we will extend the model to include other forms of 3-D imagery, particularly medical diagnostics. In addition, emphasis will be placed on expanding the linkages to include the electronic medical record and other important data and communications resources.

2.3. VRMMS Phase 3

We envision the third phase to include continued testing of our prototype lessons and expansion of the evaluation protocols. At UCSD the system will be introduced into multiple curricular settings and used under real-life conditions. In addition, we will seek collaborations with other medical institutions and expand testing into other educational venues.

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Health Care in the Information Age
H. Sieburg, S. Weghorst, and K. Morgan (Eds.)
IOS Press and Ohmsha, 1996

Chapter 24

Developing a Virtual Reality–Multimedia System for Anatomy Training

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Abstract: The University of California, San Diego, School of Medicine's Learning Resources Center is developing a prototype next-generation application for anatomy education which combines virtual reality and multimedia curricular resources. The anatomy lesson utilizes polygon-based 3-D models of the hepatobiliary system created by BioGraphics Inc. of Fort Collins, Colorado which were derived from the National Library of Medicine's Visible Human Project™ Dataset. This article describes the needs assessment, learning objectives, and preliminary design of the current prototype. The multivariate design, the development strategy for implementing functionalities, and the engineering of critical software interface components are also outlined.

1 Introduction

The Learning Resources Center (LRC) of the University of California, San Diego (UCSD) School of Medicine is actively exploring the educational applications of Virtual Reality (VR) and the potential synergism arising from combining VR with multimedia (MM) curricular resources. We have begun creating and testing multiple lessons, each targeting a specific user population (medical students, residents, or physicians), and each aimed at meeting distinct learning objectives[1]. This long range endeavor, one of the LRC's efforts to develop and implement innovative programs for medical education[2], has been named the "Virtual Reality-Multimedia Synthesis" (VR-MMS) project [3].

Our first VR-MM lessons are focused on anatomy education, and are designed to help medical students develop the internalized spatial representation of human anatomy necessary for clinical practice. The VR aspect of these lessons is an essential methodology designed to encourage exploration, discovery, and active learning by:

- freeing the student from the necessity to dissect linearly through tissue layers or to follow rigid protocols
- permitting structures to be taken apart repeatedly and examined from multiple points of view
- allowing users to investigate structures in ways not possible in the real world
- manifesting a wide range of human anatomical variation

The MM curricular aspect of the design significantly enhances the VR world, enabling students to establish and reinforce strong cognitive links to associated histology, physiology, pathology, and clinical medicine. These early efforts in the development of the VR-MM anatomy lesson, including a description of the rapid prototyping environment established to create it, are the focus of this article.

2 Developing Lessons for Virtual Environments

2.1 Needs Assessment

We began this project by specifying the educational goals and delineating the target learning outcomes. This multi-faceted process included interviews with UCSD faculty, observations of and interviews with students in the gross anatomy laboratory, analyses of traditional anatomy teaching materials (text books, dissectors, atlases, etc.), and evaluations of currently available multimedia (anatomical models, videotapes, computer programs, etc).

Following this exercise, we systematized the general requirements for UCSD's anatomy curriculum into three broad categories:

- Factual Knowledge - the identification and memorization of three dimensional (3D) structures, locations, and supply sources
- Spatial Knowledge - the development of an internalized conceptual understanding which includes functional and developmental relationships between and among structures
- Anatomical Reasoning[4] - the application of this knowledge in clinically meaningful ways

During interviews with UCSD faculty and students, certain intellectually challenging concepts were repeatedly cited as prime targets for the VR-MM instructional approach. These problematic teaching and learning areas included: visualizing potential spaces; studying relatively inaccessible areas; tracing layers and linings; establishing external landmarks for deep structures; and cogently presenting embryologic origins. Correlating gross anatomy with various diagnostic imaging modalities and portraying complex physiological processes using virtual representations were also considered highly valuable goals.

The information gleaned from this needs assessment was neither new nor surprising to individuals who have spent significant time teaching human anatomy to medical students. However, organizing these findings and articulating them as educational goals has been a critical first step for this group because it:

- focuses development efforts on the needs of the end-users, rather than the technology per se
- enables the design and development of lessons which are consistent with UCSD's curricular objectives and appropriate for integration into the culture of the course for which it is ultimately intended
- establishes a finite set of measurable learning objectives and a basis for the creation of evaluation protocols

2.2 Interface Design

The educational requirements of theVR-MM lesson interface have been specified; design and implementation are underway. The challenge of this iterative process is to create an environment which enables discovery and active learning while at the same time providing the student with the curricular structure and guidance appropriate to his or her level of understanding.

A number of instructionally-driven functionalities have been identified for inclusion in the first version of the interface. These would provide students with the capability to: label structures, substructures, and potential spaces; clarify boundaries in 3D; display appropriate multimedia resources effectively in conjunction with the 3D world; and manipulate the display to facilitate visualization. A variety of essential user requirements have also been identified including: intuitive, real-time anatomical reference planes; visual indicators of magnification; interactive tools for measuring sizes and distances; the ability to make certain objects either visible or invisible; and contextually placed requestors of curricular support.

Multiple modes of interaction have been outlined, three of which have been proposed for implementation in the first lesson. The **overview** mode would summarize concepts relevant to the anatomical region and thus provide organizational context and big picture information. The **inspection/dissection** mode, the primary mechanism of interaction in the VR-MM environment, would contain the depth and breadth of anatomical detail typically associated with traditional methods of study. The **fly through** mode, a capability which takes advantage of VR's unique opportunities, would enable students to experience an endoscopic perspective of the hepatobiliary tree.

Other interaction modes are under consideration for future implementation. The **construction** mode, part of a envisioned self-quiz component, could be used to test spatial and factual knowledge by having users build an anatomical region from its component parts. Case-based presentations and clinical vignettes are also planned for inclusion in later versions of these lessons.

3 Developing the VR-MM Learning Environment

3.1 A Rapid Prototyping Strategy

Realizing our next-generation learning system will require the synthesis of diverse instructional resources (both 2D and 3D), complex interaction technologies, and our newly developed user interface (Figure 1). This multivariate design demands that we take a flexible, iterative, and user-centric[5] approach - permitting us to incrementally implement functionalities, to respond to formative and summative evaluation, and to substitute enabling technologies and interface options as improvements become available.

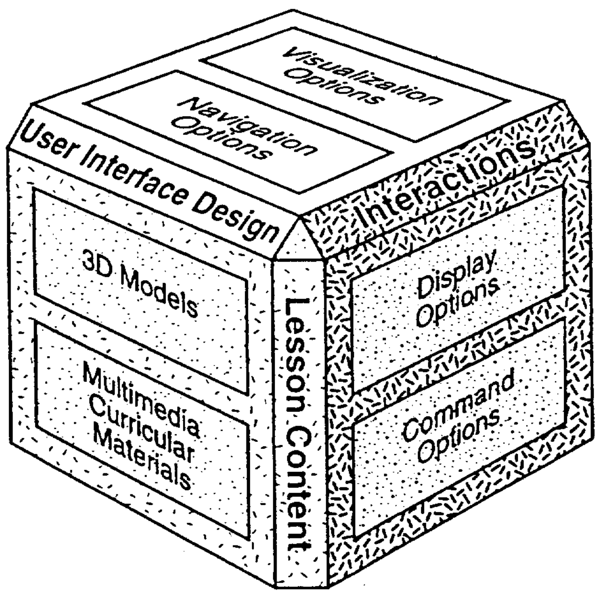

Figure 1. The VR-MM Learning Environment consists of Lesson Content, Interactions, and User Interface Design. Each facet of this multivariate system reflects multiple developmental and evaluation options and issues.

Our first prototype, focusing on the hepatobiliary system, is now being constructed using the simplest display and command options, and taking advantage of a variety of extant public domain browsers for displaying heterogeneous media. Much of the requisite imagery and associated curricular materials originate from existing School of Medicine teaching resources and the LRC's interactive library of multimedia instructional resources, MedPics©.[6] Polygon-based 3D models of the hepatobiliary system are being supplied by Biographics, Inc. of Fort Collins, Colorado, and delivered as Open Inventor™ ASCII files via ftp.

3.2 3D Model Construction

The 3D models used in our lesson are based on very high quality digital data derived from the National Library of Medicine's Visible Human Project™ cadaver. The contours for a particular structure (e.g., liver, gall bladder, veins, arteries, etc.) were hand traced on photographs of successive one millimeter sections by trained anatomists. Proprietary triangulation algorithms were then applied to connect the stacked contours of each particular structure, making 3D wireframe objects[7]. Further processing on a Silicon Graphics® workstation turned each wireframe object into a texture mapped surface model.

3.3 Software Development

The software components of the VR-MM learning environment are being engineered using an object-oriented methodology. This strategy maximizes code reuse and facilitates the adaptation of appropriate off-the-shelf technologies. An object-oriented approach also allows components to be networked beyond the physical boundary of any one workstation, while also allowing encapsulation of other components for easier integration.

A critical element of our VR-MM system is an extensible, database-driven resource catalog. Its relational database articulates relationships between and among diverse forms of instructional content - both 3D models and 2D multimedia materials. Initially written using Microsoft® FoxPro®, this component initiates searches for local or remote resources.

A second element is responsible for all display functions and is implemented using a combination of extant applications, C++ programs, perl scripts, and RPC calls. This component not only includes toolsets appropriate for displaying and manipulating multimedia, it also provides the functional **links** between the 3D VR and 2D MM components of the system. Links evoke multimedia resources specific to locations on the 3D models. Links are represented by 3D widgets whose positions, relative to the model, remain the same regardless of movement or changes in perspective or view.

A third element of this system manages all interaction between the student and the virtual world. All user and interaction tool commands are processed at this level. Silicon Graphics® RapidApp™ application builder is used to prototype all interactions. RapidApp™ is based on an object-oriented model using C++, IRIS ViewKit™, Open Inventor™, OpenGL™, Iris IM ™(the SGI implementation of OSF/Motif®) and other software libraries.

Design and development of several new tools for facilitating learning in 3D space is now underway. A **spatial guide** will provide visual reference planes for anatomical objects.

A **scaler guide** will indicate magnification with respect to the actual size of the structure or feature in view, and an **active ruler** will allow dynamic measurement of sizes and distances of objects within the virtual world.

In our initial prototype of the learning environment, touching a **link** sends a message to the database manager. For example, activating a link on the cystic duct results in the equivalent of "Find associated materials concerning the cystic duct". The database manager forms a query that returns one or more records from the relational database. Each record locates a file and identifies its media type. When multiple records are found, a selection dialogue is initiated with the student. When records are picked, a browser tool specific for displaying the chosen media is chosen and launched.

4 Refining the Prototype, the Next Steps

The work-to-date represents the first of many cycles of our rapid prototyping developmental approach. However, even though formal evaluations have not yet begun, it is already apparent that a variety of modifications will need to be undertaken. For example:

- While our current model is sufficient for learning very basic anatomy, some of the more difficult conceptual problems and salient clinical implications cannot be adequately conveyed. Consequently, the scope of the hepatobiliary world must be enlarged to include adjacent and currently unrepresented structures and features.
- A method must be determined for representing functional information not currently available from within the model. We need to ascertain whether the model can reasonably be extended or whether it is more realistic to fulfill these requirements by using alternative approaches.

As work continues, modifications will occur at all levels, including enhancements to the instructional visualization and navigation options of the user interface, expansion of 3D models and multimedia lesson content, and refinements to display and command options for interactions.

Acknowledgements

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Virtual Anatomy from the Visible Man: Creating Tools for Medical Education

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The Learning Resources Center (LRC) of the UCSD School of Medicine is actively exploring the educational applications of virtual reality (VR) and the synergism arising from combining VR with multimedia (MM) curricular resources. We see VR as a multi-faceted tool for education[1]. It can be a vehicle for building powerful and compelling simulated environments, ones in which users are free to interact without the usual constraints of the physical world. It can also be an intuitive interface for accessing information, a framework onto which students can structure and organize the seemingly endless array of disparate facts. Under a grant from the Advanced Research Projects Agency (ARPA), and in collaboration with Visible Productions (VP) of Ft. Collins, Colorado, we have begun to apply both these aspects of VR in a project called *Virtual Reality-Multimedia Synthesis*[2].

We are creating an integrated learning environment, where VR serves both as the lesson core and as the interface to diverse instructional and reference materials. In parallel, we are establishing methodologies and implementing educational outcomes analyses to evaluate the effectiveness of this environment. Individual components of the VR world and the instructional efficacy of the prototype lessons are being considered.

Human Anatomy is the focus of our prototype VR-MM environment[3], with the hepatobiliary system as the subject of our first lesson (Figure 1). The polygonal models which constitute the nucleus of our virtual world are produced and supplied by VP. These high-quality, anatomically-correct objects are obtained by tracing contours on successive slices of the National Library of Medicine's Visible Human Project™ dataset.

The dynamic environment we are developing is suitable for preclinical or clinical students. By enabling structures to be taken apart and examined from multiple points of view and in ways not necessarily possible in the real world, our environment promotes exploration, discovery, and active learning. By providing links between these virtual anatomic models and a full spectrum of MM resources, the system also encourages students to establish and reinforce strong cognitive links to associated curricular materials.

UCSD's VR-MM development efforts have been underway since 1995 and tangible results are now being realized. The initial needs assessment has been completed, the target learning outcomes delineated, and the educational goals specified. Based on these findings, the design and implementation of the user interface are now underway. A variety of instructionally-driven needs have been identified, and are now being implemented in the first lesson. These requirements include: an intuitive 3D workspace, tools for selecting and manipulating the display, and methods to facilitate visualization and conceptual learning (e.g., making certain objects visible or invisible, clarifying boundaries in 3D, and labeling structures, substructures, and potential spaces). Methods for requesting and displaying MM within the 3D world and tools to maintain anatomic orientation regardless of view or magnification are also being established (Figure 2).

The primary interaction mode (*Exploratory)* allows users to freely examine all structures within the lesson, manipulate them alone or in combination, rotate them in any direction, dolly in or out, look inside hollow structures, and change opacity to see relationship and boundaries. Users can also label structures and call up MM images.

The software components of this learning environment are complex and are engineered using object-oriented methods. One of these elements is responsible for displaying and manipulating the lesson content and for providing hot links between the VR and MM components of the system. A second element is an extensible, database-driven resource catalog for managing both 3D models and 2D MM materials. The third element manages all interaction between the student and virtual world, and includes several new tools for facilitating learning in 3D space, including a real time anatomic reference guide.

The hardware resources required to support this endeavor are well beyond the traditional computers found in most educational facilities. Consequently, under the grant from ARPA, we established the Applied Technologies Laboratory within the LRC, a strategic location which gives it full access to both local and network-based curricular resources. We have purchased and configured 3 Silicon Graphics workstations (Onyx RE2, Indigo2 High Impact, and an Indy XZ) and are integrating a variety of 3D devices such as trackers and datagloves. We have established a small but enthusiastic multidisciplinary development team to realize this endeavor.

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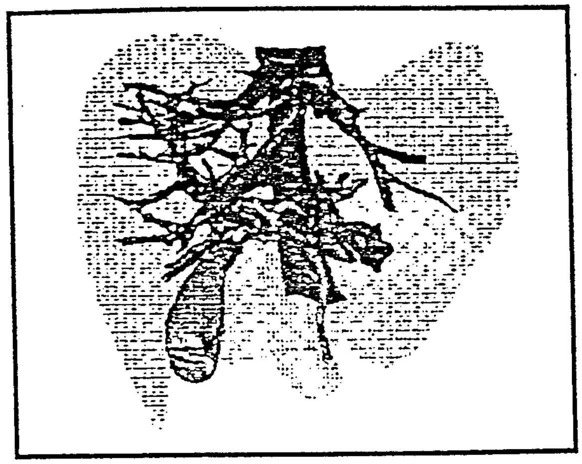

Figure 1. An anterior view of the hepatobiliary model captured from within the VR-MM learning environment. Note that the liver has been made partially opaque to allow the underlying structures to be viewed.

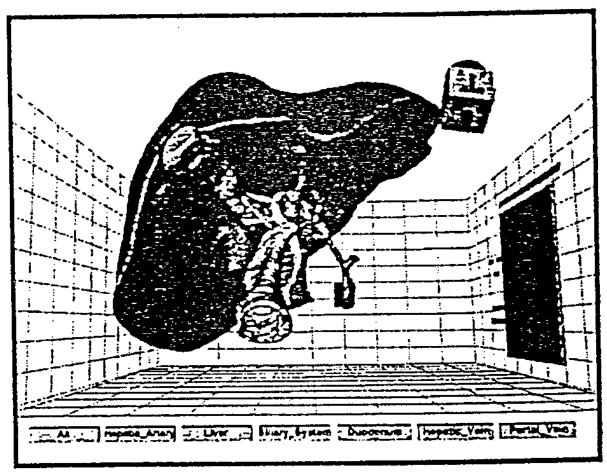

Figure 2. The VR-MM learning environment. A simple 3D grid forms an intuitive workspace. Labeled widgets provide one method by which users can interact with the anatomical model. Contextually appropriate MM is displayed on the wall of the room and the user can change orientation to better view these images. The 3D display of the head is a tool to maintain anatomic orientation regardless of view or magnification.

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A Flexible and Extensible Object-Oriented 3D Architecture: Application in the Development of Virtual Anatomy Lessons

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Abstract. "*Anatomic VisualizeR©*" represents the first application to be developed using a 3D architectural framework created at the University of California, San Diego, School of Medicine. This application combines 3D anatomic models (based on the Visible Human™ dataset) with supporting 2D media (e.g., diagnostic imagery, surgical videos, etc.) to establish a comprehensive learning environment for anatomy. "Guided lessons" are being created to address complex curricular and learning objectives. Faculty expertise is represented in these preconfigured lessons, in part through the specification of appropriate content and the incorporation of activities to enhance visualization. These lessons are an intellectual framework which ensures that clinically-relevant issues and ancillary learning opportunities are available. The curricular exercises are non-sequential and can be interrupted at any time; users are encouraged to freely explore the environment. At the core of *Anatomic VisualizeR©*'s object-oriented architecture is the ability to identify, access, view, and manipulate heterogeneous content. The capacity to query a database gateway to retrieve specified resources has been built into the application. Encapsulation of individual elements to form 3D display objects ("blocks") enables *Anatomic VisualizeR©* to efficiently manage 3D models, 2D images, text, sound, and video. The "block" paradigm also allows *Anatomic VisualizeR©* to associate contextually appropriate display characteristics and behaviors with the various content elements. For example, the anatomic model block provides the capability to "link" and "unlink" the anatomic models and to alter their transparencies. The anatomic models can be displayed concurrently with other blocks to facilitate structural comparisons. *Anatomic VisualizeR©* marks a major milestone in our developmental efforts. While lessons and database content are still not complete, we are confident that it will become the first tangible realization of our vision.

1. Introduction

Virtual Reality (VR) has captured our collective imagination, and the benefits it promises for education and training are frequently cited [1-3]. Nevertheless, transforming our vision into a tangible curricular application is a difficult and complex process. The Learning Resources Center (LRC) of the University of California, San Diego (UCSD) School of Medicine, has been working toward this goal since 1995, through a project called "Virtual Reality-Multimedia Synthesis" (VR-MMS). Under a multi-year grant from the Defense Applied Research Projects Agency (DARPA), the LRC's Applied Technologies Laboratory and Instructional Production Group have been creating a multimodal 3D environment where VR serves both as the lesson core and as the interface to diverse learning resources and medical reference materials. The educational goals, developmental

strategies, and theoretical framework underlying this endeavor have been documented previously [4-7].

This paper describes *Anatomic VisualizeR©*, the first curricular application realized under the LRC's VR-MMS project, and the Hepatobiliary Anatomy lesson which has been implemented to prototype and demonstrate its features. The discussion focuses on our new VR-based lesson paradigm and the 3D anatomic models which underlie it, as well as the *Anatomic VisualizeR©* application architecture and system configuration.

2. Instructional Development

2.1 A Guided Lesson Paradigm

We have established an instructional paradigm for our VR-based application which addresses: the specifications provided by our earlier needs assessment [8], the current standards and practices for adult education [9-10], and the unique opportunities afforded by VR. The resultant design, "Guided Lessons", combines an intuitive 3D workspace where users are free to explore, with semi-structured didactic materials furnished by faculty experts. Within these lessons, some user-driven exercises are specifically intended to help students develop working conceptual models of the human body. Other activities are directed at fostering the students' ability to apply this knowledge in clinically meaningful ways.

At the heart of each lesson is a "Study Guide" which supplies a number of important features, including: 1) an interactive Table of Contents for non-sequential access to the instructional material; 2) descriptive text which provides an organized presentation of key concepts; and 3) suggested exercises and exploratory actions (analogous to traditional dissection manuals). The Study Guide also ensures that clinically-relevant content and ancillary learning opportunities are available by including links to optional, but contextually related, resources (e.g., images of histological and pathological specimens, diagnostic studies, video clips of clinical and surgical procedures, etc.).

As a student navigates through the Study Guide, the application loads the 3D anatomic model(s) defined for the current exercise. If additional resource elements (e.g., explanatory diagrams, photographic images, etc.) are specified in the lesson plan, they are also loaded at this time. After being placed in the 3D world, elements can be selected and moved at the student's discretion according to their needs at any given time. The Study Guide's suggested activities serve as a starting point for exploration, and the descriptive outlines as a curricular framework. Anatomic models can be freely manipulated and learning by discovery is encouraged. A selection of options, always available to the user, adds richness and diversity to the sessions. For example, a student can choose to: 1) make the anatomic models appear transparent or even invisible; 2) separate (and later regroup) individual components in a group of models; or 3) request that structures be reoriented to anatomical position. Other options enable users to search for resources beyond the boundaries of the current lesson or to engage in a MEDLINE database query.

2.2 Faculty Advisory Board

In order to design and develop lessons which are: 1) consistent with the range of curricular objectives embodied by medical education from basic anatomy to the clinical clerkship level; and 2) appropriate for subsequent integration into academic medical

settings, we established a Faculty Advisory Board. These individuals, with combined expertise in medical education, anatomy, physiology, pathology, radiology, medicine, and surgery, provide ongoing expertise and guidance to the project. This advisory board represents not only UCSD's curriculum, but includes faculty drawn from other medical schools around the world.

3. 3D Anatomic Models

The high-quality, anatomically-correct, polygonal models used in the program have been produced and supplied by Visible Productions of Fort Collins, Colorado [11]. These extremely realistic models were derived from serial sections of the National Library of Medicine's Visible Human Project™ dataset using a proprietary triangulation algorithm to connect traced contours [12]. Prior to incorporation into *Anatomic VisualizeR©,* several models were further modified using Visual Productions' VPSculpt© program in order to reduce their file size, or to separate larger structures into smaller constituent parts.

4. Application Architecture

4.1 Blocks

Anatomic VisualizeR© provides an extensible user interface for manipulating objects within the 3D environment. Central to its implementation is the concept of defining and using resource "blocks", self-contained 3D objects capable of type-specific behaviors. Encapsulation of any and all individual lesson resource elements into blocks enables *Anatomic VisualizeR©* to efficiently manage and concurrently present different types of media (e.g., 3D models, 2D images, video clips). Any block possesses several core functionalities, including the ability to be attached or removed, selected or de-selected, iconicized or de-iconicized, and moved in six degrees of freedom.

In addition to these core features, the 3D anatomic model blocks have been endowed with type-specific functionalities relevant to their use within lessons. For example, their display transparency can be manipulated, allowing their appearance to change from opaque to transparent to invisible. Anatomic models can be selected not only individually, but simultaneously, in any combination, as part of a group. Individual components of a group can be separated ("unlinked") and then regrouped ("linked") into a different group. Moreover, models within groups can maintain proper anatomical position with respect to each other. The user can freely manipulate individual or grouped anatomic models, which can be reoriented to anatomical position on request. In addition, a 3D spatial reference tool is displayed within the lesson environment whenever model blocks are present. This tool is intended as a simple, intuitive way to help the user keep track of anatomical orientation regardless of view.

4.2 Database Gateway

At the core of *Anatomic VisualizeR©*'s object-oriented architecture is the ability to identify, access, view, and manipulate disparate types of lesson resources [13,14]. The application is able to dynamically retrieve and present current (possibly updated) lesson resources while following the organizational hierarchy defined by the lesson's Study Guide.

This is achieved by taking advantage of its built-in capacity to query a database gateway and retrieve specified resources.

The LRC's MEDIACAT curricular resource database is currently implemented in Microsoft FoxPro™. It resides on a Windows NT™ server where a World-Wide-Web (WWW) database gateway server application accepts and services database queries. Searches by media type as well as by subject area are supported. Search results are given as Uniform Resource Locator (URL) format filenames.

4.3 3D User Interface Development with FACET

A 3D block manager which we call FACET implements the core functionality accorded every block. FACET blocks exist for the following specific resource types: text, 3D anatomic models, 2D images, video clips, sound files, and MEDLINE literature searches. We have been able to organize interactions within the 3D world by developing tools which work with FACET to implement 3D presentation and user interface capabilities. Specialized managers as well as a growing list of 3D "widgets" (described below) have been created [15].

One of the specialized managers is the Anatomic Model Manager. It handles functionality global to any anatomic model, starting by loading 3D anatomic models (in Open Inventor™ [16,17] format) into anatomic model blocks which can then be manipulated by FACET. The Anatomic Model Manager also implements any global realignment of anatomic models into anatomical position, as well as grouping, linking, and unlinking component anatomic models.

Another specialized manager is the Lesson Manager. It acquires and places all curricular resource materials in the 3D world. It provides intelligent navigation through lesson materials by managing the available resources according to the context provided by the Study Guide.

The Environment Manager is similar, but controls access to system-wide resources available to the application at any time. Requests to query the MEDIACAT curricular resource database are fielded by the Environment Manager, which also handles access to sound I/O and can turn the application's reference grid on and off.

In addition to registered event handlers, blocks allow for the handling of content-specific events depending on block type. These events are activated by node selection along an Open Inventor™ scenegraph path. In this way, changes to an individual anatomic model block's opacity, responses to a video block's player controls, or the selection of "previous" or "next" from a multiple image block can be implemented.

FACET, specialized managers, and resource blocks all understand and use newly created 3D widgets from our growing list. 3D widgets are objects like selectable lists, scrollbars, and buttons common to any windows-based user interface, except they are designed and implemented for 3D presentation and interaction. Some of these 3D widgets have been combined into "virtual" blocks within the 3D world for the purpose of providing a specific user interface. For example, the Study Guide is a virtual block that "listens" for user resource selection or navigation commands and then forwards these commands to the Lesson Manager.

4.4 FACET and Device I/O

FACET supports an extensible assortment of user interface devices and their associated device drivers via a simple central I/O configuration file. Any valid user

interface command is defined in this simple ASCII format file as event definitions and associated command-to-action mappings. Using this file, commands global to the application may be implemented by several distinct device drivers. Commands relevant only to a particular I/O device may also be defined. For example, either the Left-Mouse-Button or a PinchGlove Index-finger-with-thumb gesture can be used to select a block. Extensions to device drivers for changing device I/O characteristics are well encapsulated and easy to make. Events within this configuration file are named and associated with command actions. Named events are passed to FACET's Event Manager for routing.

FACET's Event Manager queries several different kinds of event handlers (including the specialized managers mentioned in section 4.3) with the command/event name until a matching handler can be located. Using blocks with events allows *Anatomic VisualizeR©* to flexibly associate contextually appropriate interaction, display characteristics, and behaviors with extensible lesson content.

5. Hardware and Configuration

Anatomic VisualizeR© currently supports two types of visual display: monoscopic CRT or stereoscopic CRT using StereoGraphics CrystalEyes® eyewear. Hand motion tracking is provided using Ascension Flock of Birds™ trackers. Combining hand gestures generated by the Fakespace PINCH glove system with hand position information from the Ascension trackers, the application allows the user to grab any block and move it in 3D space. Interface devices are used in combination with Application Toolbar options to provide the syntax for user interaction with the application. Different gestures and motions are being evaluated for their ease of use. Traditional keyboard and mouse interactions are also supported.

6. Summary

Anatomic VisualizeR© marks a major milestone in our developmental efforts. Although lesson development and database content expansion are ongoing, we are confident that it will become the first tangible realization of our vision.

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Assessing a VR-based Learning Environment for Anatomy Education

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Abstract. The purpose of the research proposed herein is to develop an empirical, methodological tool for the assessment of visual depth perception in virtual environments (VEs). Our goal is to develop and employ a behaviorally-based method for assessing the impact of VE design features on the perception of visual depth as indexed by the performance of fundamental perceptual-motor activities. Specifically, in this experiment we will assess the affect of two dimensions of VE system design - (1) viewing condition or "level of immersion"; and (2) layout/design of the VE - on the performance of an engaging, game-like task. The characteristics of the task to be employed are as follows - (1) it places no demands on cognition in the form of problem solving, retrieval of previously learned information, or other analytic activity in order to assure that (2) variations in task performance can be exclusively attributed to the extent to which the experimental factors influence visual depth perception. Subjects' performance will be assessed in terms of the speed and accuracy of task performance, as well as underlying dimensions of performance such as workload, fatigue, and physiological well being (i.e., cybersickness). The results of this experiment will provide important information on the effect of VE immersion and other VE design issues on human perception and performance. Further development, refinement, and validation of this behaviorally-based methodology will be pursued to provide user-centered design criteria for the design and use of VE systems.

1. Introduction and Purpose

The University of California, San Diego (UCSD) School of Medicine has been actively exploring the use of virtual reality (VR) in medical education[1] through the development of an application named "VisualizeR©". A prototype of this multi-modal virtual environment (VE), developed to support the teaching and learning of human anatomy, has reached a level of maturity which will soon enable it to be expanded for use in actual curricular settings[2,3].

UCSD's VisualizeR© architecture[2] supports three visual display configurations: non-immersive (regular color CRT monitor), partially-immersive (stereographic CRT with shutterglasses) and immersive (Head Mounted Display). Moreover numerous VE layouts (position and availability of tools, resources, etc.) and depth cues (presence of shadows,

perspective grid, etc.) are also possible within each of these display configurations. However, before further development and implementation can proceed, it is critical that we obtain additional information concerning the cost-benefit of VisualizeR© and its various configuration options.

We are therefore embarking on a series of experiments which will provide empirical data concerning the impact of these VE system design choices on perception, performance of perceptual-motor tasks, educational outcomes, and training transfer. The first of these studies, scheduled to begin in early 1998 and outlined here, will focus on the perception of visual depth, addressing the impact of viewing condition or "level of immersion" and the influence of environmental depth cues (e.g., shadows, size, etc.).

2. Methods

2.1 Experimental Design

A within-subjects factorial design will be used to assess the effect of two dimensions of VE system design on the performance of a fundamental perceptual-motor task (See section 2.2 Task Description). Four Equipment Configurations, representing three viewing conditions or levels of immersion, will be tested:

(1) Non-immersive configuration (regular color monitor - "CRT")
(2) Partially-immersive configuration (stereographic CRT with shutterglasses "Shutterglasses")
(3) Immersive configuration (head mounted display - "HMD #1")
(4) Immersive configuration (head mounted display - "HMD #2")

In addition, two different Environmental Layouts will be tested:

(1) With depth cues
(2) Without depth cues

The crossing of four levels of Equipment Configuration and two levels of Environment Layout will result in eight unique experimental conditions. All subjects will be tested in all eight conditions. Presentation of experimental conditions will be counterbalanced in order to guard against order effects. A total of ten replications or trials per condition will be performed by each subject. Therefore, each subject will perform a total of 80 trials in the experiment.

2.2 Task Description

The perceptual-motor task employed in these studies has been carefully crafted to rely only on the ability of the subject to accurately perceive objects in three dimensional (3-D) space. It is also simple enough to assure that prior learning and/or different levels of familiarity with more specialized tasks do not complicate interpretation of the results. This is an important consideration in order to assure that differences in task performance can be attributed exclusively to differences between the experimental conditions. The task is game-like and intended to be engaging and intrinsically motivating so as to help maintain the subjects' interests and efforts in these experiments. A "scoreboard" of "best performers" will also be maintained in order to further motivate subjects to do their best.

The subjects will be asked to perform tasks in apparent three-dimensional space. They will be required to accurately localize: (1) a virtual object in relation to other virtual objects, and (2) the location of a virtual "hand" or cursor that responds to movements of their own hand with relation to various virtual objects. For example, a subject might be instructed (when given an appropriate signal such as a tone), to "reach out" in virtual space, "grasp" an object (e.g., "the green cube"), and place it somewhere else with respect to other virtual objects (e.g., "in between the red sphere and the blue pyramid"). To make the tasks progressively more difficult, the size of these virtual objects will decrease and the speed with which they "appear" in the VE will increase as a function of time.

2.3 Performance Measures

All subjects will be asked to perform several clinical tests of depth perception before undertaking the performance tasks using VisualizeR©. These data will be used as covariates for the performance data, to account for individual differences in performance attributable solely to physiological and psychological/experiential factors affecting depth perception. The availability of these clinical parameters will add greater power to the design of the study since it will remove a source of variance in the data that might otherwise be incorrectly attributed to error variance.

The measures of performance (See Table 1.) to be used during the VR-based protocol will include:

- Duration of task performance (from "go" signal to successful completion of task)
- Accuracy of performance as indexed by the number and type of errors made in the performance of the task
- Cognitive and physical workload as indexed by the NASA Task Load Index (TLX)[4] workload measurement instrument
- Fatigue as indexed by the Yoshitake Fatigue Scale[5]
- Cybersickness as indexed by the Kennedy Simulator Sickness Questionnaire[6].

Table 1. Dependent Variables with Respect to Immersion and Environmental Layout

<table>
<tr><th rowspan="2"></th><th colspan="4">LEVELS OF IMMERSION</th></tr>
<tr><th>CRT</th><th>Shutterglasses</th><th>HMD#1</th><th>HMD#2</th></tr>
<tr><td>With Depth Cues</td><td colspan="4" rowspan="2">• Depth Perception
• Performance:
- Duration of task
- Accuracy of performance
- Cognitive and physical workload
- Fatigue
- Cybersickness
• Binocular Convergence
• Attention</td></tr>
<tr><td>Without Depth Cues</td></tr>
</table>

Using Video-Oculography (VOG), we will also obtain measures of binocular convergence during the performance of tasks. This microelectronic technique uses small CCD video cameras to capture a front image of each eye and track the direction of gaze. The signals are sent to a video recognition card on a computer which processes the video images to find the center of each pupil and then calculates coordinates of the pupils relative to the camera image. These coordinates can be generated in real time or stored in memory for post-hoc analysis. The micro cameras used for VOG are mounted onto an HMD and provide the gaze coordinates while a user is viewing images in the VE. For stereo images, these binocular recordings will enable us to determine the convergence angle, or the angle between the lines of gaze of each eye. This measure of depth, in combination with the gaze coordinates, will allow us to track where the subject is attending in depth as well as horizontally and vertically.

The focus of our subjects' attention can also be determined using the same binocular VOG techniques. The functional measures of the subject's gaze coordinates can be used to monitor which objects are attracting focus in an HMD for our particular application. The tendency of the visual system is to focus and align at the same distance. For example, if the subject were focused at an object at infinity, the eyes would be aligned to be parallel. However, in a fixed focus HMD where an object is presented in stereo, ie. with stereo disparity, the eyes may align to a different distance than the eyes are focused at. The research question thus becomes, in a stereo display with fixed focus, do the eyes tend to align with objects in a focus plane more than they would in the real 3D world? Our specific measures are the percentage of time at a given convergence angle in relation to which objects are in the scene. This measure can be used to determine the value of different 3D presentations.

2.4 Subjects

Subjects will be recruited from the student population of the University of California at San Diego Medical School.The use of medical students in the current experiment will permit the development of: (1) a cohort of subjects to be used in subsequent studies that are more specifically tied to educational outcomes and training transfer studies, and (2) a database of perceptual-motor performance indices for comparison to non-specialized populations. Prior to conducting these experiments, approval was sought and received from the Human Subjects Committee at the University of California - San Diego.

3. Discussion

The accurate perception of 3-D space is critical to the performance of nearly all complex human activities. It is also essential to the acquisition of many dimensions of knowledge and skill, such as the learning and application of functional human anatomy. When developing complex spatial domains in virtual environments, two characteristics of VE technology may be exploited: (1) visually (as well as haptically, auditorally, etc.) rendering objects in compelling 3-D representations, and (2) interacting, in real time, with rendered objects in apparent 3-D space. Both of these possibilities offer potential avenues by which the acquisition of spatially-based cognitive and perceptual-motor skills can be accelerated.

However, the factors affecting accurate perception of depth in virtual environments are by no means agreed upon. Nor is there substantial agreement as to how variations in VE system design features and their interactions affect the perception of visual depth. For example, how is depth perception affected when field of view is enlarged and optical resolution is degraded? The issue becomes even more complicated when factors associated with the performance of individual tasks (e.g., anatomical dissection, anastomosis, etc.) are taken into account. An essential aspect of depth perception in one application may be utterly irrelevant in another.

Another key question is whether or not "immersion" or "presence" is critical in promoting the behavioral goals of the learning system. For instance, would a greater sense of immersion within Anatomic VisualizeR© help, hinder, or have no effect on a medical student's ability to learn functional anatomy? While some educators propose that the benefits of VR cannot be realized without a fully immersive learning environment,[7,8,9] it is more likely, but still unproven, that the answer is heavily application-dependent. Until outcomes analyses delineate the merits and limitations of different interface options, the specifications required to achieve any given goal will remain a function of merely practical and philosophical considerations.

The experiments which we are about to initiate are intended to help understand perception and learning in VE and to elucidate the basic characteristics necessary to build efficient and effective systems. To realize this goal, we believe that the logical first steps are to understand the users' perception of depth in virtual space and to elucidate the similarities and differences among the various display configurations and visualization options. These studies are also intended as the first step in the development of a methodology that will provide user-centered, performance-based criteria for system developers seeking to determine tradeoffs between equipment design options (and associated cost and maintenance issues) and human performance.

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Anatomic VisualizeR© -Virtual Anatomy For Education

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Abstract

"Anatomic VisualizeR©" represents the University of California, San Diego, School of Medicine's first Virtual Reality-based educational application. Developed under a grant from the Defense Advanced Research Projects Agency (DARPA), Anatomic VisualizeR© is a virtual world which could provide a compelling learning environment and a paradigm for navigating through the world of medical information. It combines 3-D anatomic models (based on the Visible Human™ dataset) with supporting 2-D media (e.g., diagnostic imagery, surgical videos, etc.) to establish a comprehensive learning environment for clinical anatomy. This dynamic environment is suitable for preclinical or clinical students. The curricular content is based on clinical simulations and promotes exploration, discovery, and active learning by enabling structures to be taken apart and examined from multiple points of view and in ways not necessarily possible in the real world. It also encourages students to establish and reinforce strong cognitive links to associated curricular materials by providing links between these virtual anatomic models and a full spectrum of multimedia resources.

Anatomic VisualizeR© provides a flexible and extensible user interface for manipulating objects within the simulated 3-D environment. At the core of its object-oriented architecture is the ability to identify, access, view, and manipulate disparate types of lesson resources, accomplished through the creation of encapsulated lesson elements called "blocks". A 3-D block manager called FACET implements the core functionality accorded every block. FACET blocks exist for a variety of medical resources, for exploratory tools that work with those resources, and for specialized text organization and presentation blocks. The application architecture is designed to enable complex multimodal simulations with dynamic retrieval and presentation of lesson resources while following the knowledge hierarchy represented by the lesson's Study Guide. Hand and head motion tracking combined with gestural input allow the user to grab any block and move it in 3-D space. The Study Guide as well as Toolbars provide the syntax for users to navigate, manipulate, and interact with the application and its resources. Anatomic VisualizeR© supports three types of visual display: monoscopic CRT, stereoscopic CRT, and full immersion. Studies designed to elucidate the relative merits of VR-based teaching systems and the role of interface design on educational outcomes are underway.

Introduction

In 1995 the Learning Resources Center (LRC) of the University of California, San Diego (UCSD) School of Medicine, began a multi-year study to investigate the educational application of advanced technologies, particularly Virtual Reality (VR) based simulation. Supported by a grant from the Defense Advanced Research Projects Agency (DARPA), the LRC began development of a virtual world which would provide a compelling learning environment and a paradigm for navigating through the world of medical information. The LRC's design also incorporated extant multimedia (MM) learning resources and reference materials derived from traditional books, atlases, image banks, databases, animations, & video. This strategy, called VR-Multimedia Synthesis (VR-MMS), was

established as a method of adding depth & clarity to the virtual environment (VE). VR-MMS was envisioned as a strategy for enabling the learning of subjects requiring mastery of elaborate 3-D models and integration of spatial knowledge with large quantities of diverse pedagogic materials. (Hoffman 1995a,b)

PROJECT DESCRIPTION

UCSD's multi-modal design has been realized in a flexible and extensible object oriented 3-D software architecture, called "VisualizeR"© (Hoffman et al 1997). The prototype curricular application, now under development, is being created to support the study of human anatomy by preclinical medical students (Hoffman et al 1996).

Early in the development process, a formal assessment of faculty and student needs for anatomy training at UCSD was undertaken (Hoffman 1996). In addition, learning issues during the first two (preclinical) years of medical school were investigated, as were the subsequent applications of this knowledge during the third and fourth (clinical) years. Once this analysis process was completed, the educational goals of the project were defined, broad learning objectives were specified, and the foundation for the subsequent evaluation protocols were established. The application developed to fill these requirements, the first application realized using UCSD's VR-MM architecture, is now called "Anatomic VisualizeR©".

The instructional paradigm of Anatomic VisualizeR© addresses the needs identified in the earlier formal assessment, while recognizing current standards and practices for adult education (Merriam and Cafferella 1991) (AAMC 1993), and capitalizing on the unique opportunities afforded by virtual worlds and simulation. The program provides an intuitive VE where users are able to "dissect" 3-D anatomic models while accessing supporting resource elements (explanatory diagrams, diagnostic images, surgical videos, literature searches, etc.). Students are freed from the need to dissect linearly through tissues layers or to follow rigid protocols. The simulation enables them to investigate structures in ways not possible in the real world. The size or scale of an object can be changed, the opacity of an organ modified to see its internal architecture, or an endoscopic perspective assumed to view the interior of hollow structures. At the heart of each Anatomic VisualizeR© exercise is a "Study Guide" which organizes links between medical resources and didactic material. The Study Guide supplies a number of important bridges and anchors including: 1) an interactive Table of Contents for flexible non-sequential access to the case material; 2) descriptive text which provides an organized presentation of key concepts; and 3) suggested exercises and exploratory actions. These case-based lessons are designed to encourage active learning while helping students to create a symbolic framework for anatomical knowledge as well as to establish a context in which to integrate clinical skills and reasoning. (Rosse 1995)

APPLICATION ARCHITECTURE

Anatomic VisualizeR© provides an extensible user interface for manipulating objects within the 3-D virtual world (Hoffman et al 1997). The encapsulation of individual lesson components into "blocks" enables Anatomic VisualizeR© to efficiently manage and concurrently present different types of resources. Blocks represent either specific resources (e.g., 3-D models, 2-D images, video clips), exploratory tools (e.g. Cut plane viewer, 3-D space draw, flag marker), or collected textual material (e.g. study guide, student notebook). All blocks have core functionalities such as the ability to be attached or removed, selected or de-selected, iconicized or de-iconicized, and moved in six degrees of freedom. In addition, the 3-D anatomic model blocks have type-specific functionalities relevant to their use within lessons. For example, their display transparency can be manipulated, allowing their appearance to change from opaque to transparent. Anatomic models can be selected not only individually, but simultaneously, in any combination, or as part of a group. Individual components of a group can be separated ("unlinked") and then regrouped ("linked") into a different group. Moreover, models within groups can maintain proper anatomical position with respect to each other. The user can freely manipulate individual or grouped anatomic models, which can be reoriented to anatomical position on request. In addition, a 3-D spatial reference tool is displayed within the lesson environment whenever model blocks are present. This tool is intended as a simple, intuitive way to help the user keep track of anatomical orientation regardless of view.

The 3-D polygonal models which constitute the nucleus of VE resources have been produced and supplied by Visible Productions, of Fort Collins, Colorado (McCracken et al 1991). These objects were obtained using a proprietary triangulation algorithm to connect contours traced from successive slices of the National Library of Medicine's Visible Human Project™ dataset (Ackerman et al 1995).

At the core of Anatomic VisualizeR©'s object-oriented architecture is the ability to identify, access, view, and manipulate disparate types of lesson resources while using the same interface paradigm. The application is able to dynamically retrieve and present current (possibly updated) lesson resources of any type while following the organizational hierarchy defined by the lesson's Study Guide. This is achieved by taking advantage of its built-in capacity to query a database gateway and retrieve specified resources. The LRC's MEDIACAT curricular resource database is currently implemented in Microsoft FoxPro™. It resides on a Windows NT™ server where a World-Wide-Web database gateway server application accepts and services database queries. Searches by media type as well as by subject area are supported. Search results are given as Uniform Resource Locator (URL) format filenames.

3-D User Interface Development with FACET

A 3-D block manager named FACET implements the core functionality accorded every block, no matter what it contains. In addition to medical resource blocks, we have been able to organize interactions within the 3-D world by developing exploratory tool blocks to work with those resources as well as specialized text tool blocks that improve and refine 3-D presentation and user interface capabilities.

Three dimensional anatomic models (in Open Inventor™ format (Emmerik 1991) (Howard et al 1993) are loaded into anatomic model blocks controlled by FACET. So far, exploratory tools such as the cut-plane viewer, 3-D space draw, and flag marker have been developed. These tools work only with anatomic models and are only available when models are present. Both resources and the tools affecting them are controlled by FACET.

FACET, specialized tools, and resource blocks all understand and use newly created 3-D widgets. These are objects like selectable lists, scrollbars, and buttons common to any windows-based user interface, except they are designed and implemented for 3-D presentation and interaction.

Some of these 3-D widgets have been combined into text blocks within the 3-D world for the purpose of providing a specific user interface. For example, the Study Guide has the ability to "listen" and then act on user selection commands or queries in order to provide a cognitive map linking resources with didactic material.

Facet and Device I/O

FACET supports an extensible assortment of user interface devices and their associated device drivers via a simple central I/O configuration file. Any valid user interface command is defined in this simple ASCII format file as event definitions and associated command-to-action mapping. Using this file, commands global to the application may be implemented by several distinct device drivers. Commands relevant only to a particular I/O device may also be defined. Device drivers are well encapsulated so that the addition of new devices as well as modifications to existing device commands are as easy as possible to make. Events for a particular device are named and associated with command actions. Named events are passed to FACET's Event Manager for handling. Using blocks with events allows Anatomic VisualizeR© to flexibly associate contextually appropriate interaction, display characteristics, and behaviors with extensible lesson content, while letting FACET maintain control of the visual display.

Platform, Hardware and Configuration

Anatomic VisualizeR© is written in C++ using Open Inventor libraries. It has been run on Silicon Graphics Onyx REII, HIGH Impact, and O2 workstations. Faster configurations support higher frame rates and greater numbers of concurrently loaded 3-D models. Frame rates depend on multiple factors including number of polygons in models and model sets, and choice of display. Currently, three visual display configurations are available: CRT, stereoscopic CRT using StereoGraphics CrystalEyes® eyewear, or Virtual Research V6 Head Mounted Display. Hand and head motion tracking is provided using Ascension Flock of Birds™ trackers. Combining hand gestures generated by the Fakespace PINCH glove system with hand position information from the Ascension trackers, the application allows the user to grab any block and move it in 3-D space. Interface devices are used in combination with Application Toolbar options to provide the syntax for user interaction with the application. Different gestures and motions are being evaluated for their ease of use. SensAble Technologies' PHANToM™ and Immersion Corporation's MicroScribe-3D haptic devices are also being evaluated.

Summary

While still in its early stages of development, Anatomic VisualizeR© marks a major milestone in the VR-MMS efforts. Current efforts are focused on expansion of

lessons and database content, and refinement of the user interface and configuration options. Studies designed to elucidate the relative merits of VR-based teaching systems and the role of interface design on educational outcomes are underway. Ultimately, Anatomic VisualizeR© will be implemented within UCSD's preclinical anatomy curriculum.

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Anatomic VisualizeR: Realizing the Vision of a VR-based Learning Environment

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Abstract. The University of California, San Diego's Anatomic VisualizeR© project has reached another milestone. As the period of DARPA-funded research and development comes to a close, UCSD's VR-based learning environment has matured to the point where curricular implementation is now underway. In this presentation, we will reflect on the process by which lessons in this virtual environment are realized, highlight the results of ongoing 3-D perception studies, and describe examples of how Anatomic VisualizeR© is being used in medical school anatomy and high school biology classes. To conclude, we will outline the future of this project which will include full scale curricular implementation, learning outcomes assessment, and dissemination through industrial and academic partnerships.

1. Introduction

The University of California, San Diego (UCSD) School of Medicine has been actively exploring the education potential of Virtual Reality (VR) and has focused on the development of next-generation instructional systems which combine VR with multimedia (MM) curricular resources. Now nearing the conclusion of the Defense Advanced Research Project Agency (DARPA)-funded research and development phase, it seems fitting both to reflect back on the process by which efforts have progressed as well as to highlight current activities and future directions.

2. Purpose and Methods

UCSD's VR-multimedia synthesis (VR-MM) design was first described through a video mock-up at the "Medicine Meets VR 2" conference in January 1994 [1]. The following year, the developmental approach for VR-MM lessons was outlined, with particular emphasis placed on addressing pedagogical issues [2,3]. While conceptual (open learning) or operational (task training) simulations were possible, UCSD chose the former, and by January 1996, the first working model of the VR-MM open learning environment was established [4,5]. The challenge was to develop a 3-D user interface paradigm that would support exploration and discovery-based learning while still providing the curricular structure necessary to ensure successful learning outcomes [6]. The current instructional design and the underlying multi-modal 3-D software architecture (VisualizeR©) were achieved by the beginning of 1997 and are described elsewhere [7].

2.1 *Selection of Subject Domain*

The scientific domain selected for UCSD's first VisualizeR© lessons was human anatomy since it represented one context in which a VR-based strategy appeared both achievable and apropos. Once developed, virtual anatomy lessons would be appropriate for use either as adjuncts to or as replacements for the current practices in anatomy education -- a combination of lectures and laboratory dissections. While still considered the "gold standard" against which alternatives are judged, standard educational methods can fall short of instilling the requisite 3-D conceptualization, retention, and application of anatomic knowledge to clinical problem solving [8,9]. The pedagogical challenges are further complicated by reduced hours available to anatomy education [10,11] and a growing need to find alternatives for cadaver and animal specimens resulting from scarcity, costs, aesthetics, and environmental concerns [12]. Strategies such as plastic specimens, videos, and multimedia computer programs have utility, but do not seem to provide fully satisfactory dissection alternatives [8].

2.2 *Instructional Design Issues and Solutions*

The development of VisualizeR-based anatomy lessons (Anatomic VisualizeR©) began with particular attention to the pedagogical and logistical issues described above[4,7]. In addition, efforts were made to leverage the unique, and relatively unexplored, capabilities afforded by a 3-D virtual learning environment. The design of Anatomic VisualizeR© evolved considerably during the initial years of its development, and a variety of human-computer interfaces were investigated. The present implementation realizes the project's goal of a VR-based environment promoting discovery and experience-based learning of anatomic structures and concepts. The multi-modal characteristics of Anatomic VisualizeR©, which have evolved out of the initial VR-MM paradigm, have facilitated the development of important instructional capabilities. Presentation of lesson resources in VR affords students the ability to intuitively manipulate and explore anatomic models using tools and techniques beyond those possible in the real world. The MM resource elements (diagrams, images, text, video, MEDLINE, etc.) add richness and depth to the learning experience and can be used to facilitate strong cognitive links between structural anatomic knowledge and associated didactic materials.

The balance between student-centered, discovery-based learning and curricular structure was achieved though the combined use of a Study Guide and Application Toolbars. The virtual Study Guide provides a mechanism for directed mentoring and can be used to organize key concepts, load and unload lesson resources, suggest student exercises, and provide selectable links to contextually relevant resources from multiple domains of medical science (histology, pathology, radiology, etc.). Toolbar options for anatomic models confer on the student the ability to: link and unlink anatomic organs, change organ transparency or size, dynamically create cross sectional views using a clipping plane, measure sizes and distances with an virtual ruler, label structures with a flag marker, and draw lines and simple objects using a 3-D drawing tool. Anatomic orientation of displayed organs is indicated regardless of their placement, orientation, or magnification within the virtual environment. In addition to anatomy-specific user tools, other Toolbar options provide certain environmental controls. Options to turn on and off a 3-D perspective grid, to turn on and off the Study Guide, and to search for and load additional resources have proven extremely useful.

The Study Guide is intended to be uniquely customized by faculty authors for each anatomy lesson module. The Lesson Editor developed for Anatomic VisualizeR©, while still rudimentary, provides a simple graphical user interface that can be used to "storyboard" and then try out lessons (Figure 1). Faculty can specify the sequence of Study Guide pages or tabbed sections, and each page can specify what lesson resources are to be loaded where. Page headers and text can be entered, and buttons with anchors for either accessing "Clinical Correlates" or changing scene appearance can be inserted. Lesson Editor output is an ASCII file which can also be further modified using any text editor.

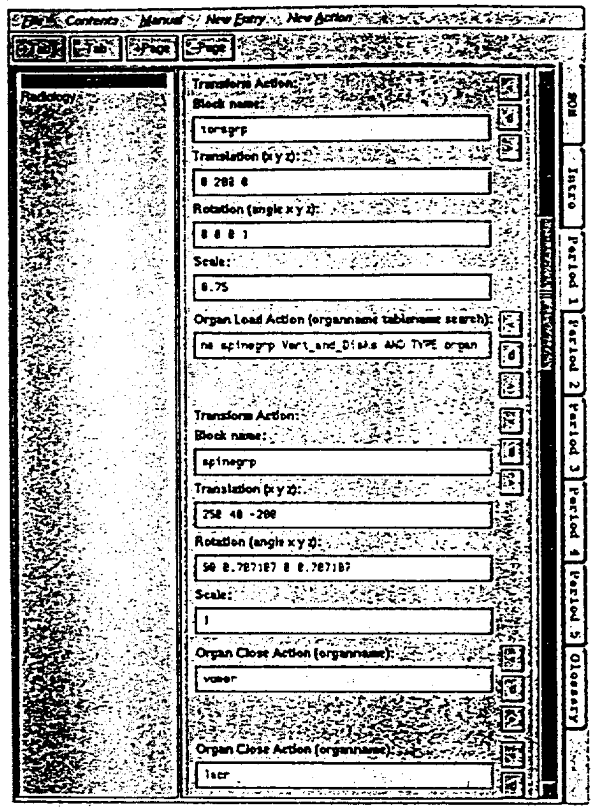

Figure 1: Lesson Editor. Elements on the "Thoracic Skeleton" page in tabbed section "Period 1", showing placement, scaling, loading and unloading of anatomic models.

2.3 3-D Models

Anatomic VisualizeR© can utilize 3-D polygonal models derived from a wide variety of sources. After reviewing a variety of options, models derived from the National Library of Medicine's Visible Human Project™ dataset [14], and supplied by Visible Productions, Inc., were selected.

Making these anatomic models fulfill both technical and educational requirements was an unexpected challenge. Although the models were of very high quality, major implementation issues quickly emerged. First, a finite number of polygons could be moved and manipulated at one time, depending on technical limits such as the graphics capability of the machine and whether the display is monoscopic or stereoscopic. This impacted the size and number of organs that could be concurrently used in any one lesson scene. Efforts to globally "decimate" the number of polygons frequently reduced the level of structural fidelity below that required to meet instructional needs and only served to exacerbate faculty concerns regarding the teaching value of certain idiosyncratic anatomic elements. After careful consideration of the problem and potential solutions, an alternative method for modification of the anatomic models was devised: a medical illustrator was tasked to use VPSCULPT© [15] to optimize each anatomic organ model. Model structures were sculpted - facets were selectively added and removed - selected areas were decimated, and normals were changed where necessary. An example of one particularly difficult structure before and after processing is illustrated in Figure 2.

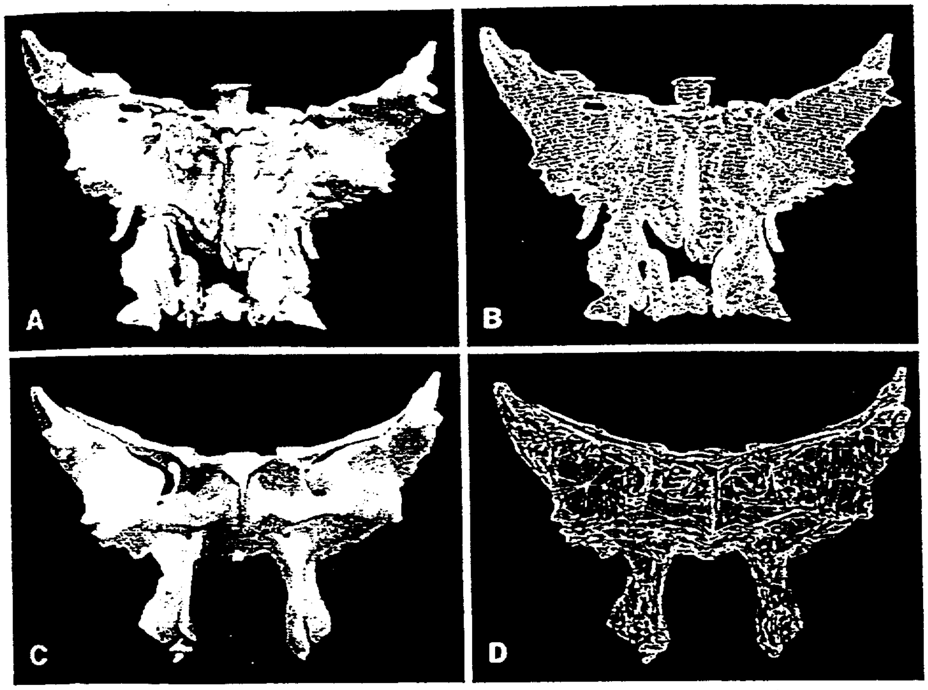

Figure 2: Anatomic Model Optimization. Model of the sphenoid bone of the skull as received (A) and after sculpting to make the structure anatomically accurate (C). Corresponding wireframe representations visually show polygons before (B) and after decimation (D).

3. Results

3.1 *Virtual Environment Choices and Evaluation*

Anatomic VisualizeR©'s architecture can support multiple types of visual display (monoscopic CRT, stereoscopic CRT, and head mounted display (HMD)) and input options (gloves with motion trackers, 3-D trackball, and mouse). With so many supported choices, parallel efforts have consequently been directed at characterizing the effects of these option choices on student perception and performance. The first of these studies has been sponsored by the Office of Naval Research to examine 3-D perception in UCSD's virtual learning environment [16]. Medical student subjects were asked to use gloves and trackers to select a geometric object appearing randomly at different depths on the display. Task performance was then compared across four different VR device configurations and using four different user interface layouts. Preliminary analysis of these data suggest that performance of a very simple task is not highly influenced by the characteristics of the VE and that students can readily accommodate to different VR learning environments. Further studies are being planned to examine more complex and realistic tasks wherein learning outcomes will also be considered.

3.2 *Anatomic VisualizeR© in the Classroom*

The process of implementing and assessing virtual anatomy lessons has begun. The first classroom application of Anatomic VisualizeR© has occurred after the creation of a lesson entitled "VR Laboratory for Advanced High School Anatomy". This high school

level virtual anatomy lesson has been piloted even while the 3-D models and another lesson were still being optimized for the medical school anatomy curriculum. The lesson modules for the high school students were authored, in large part, by their teacher working in the School of Medicine's Learning Resources Center on a summer faculty development fellowship. The process began with a brief orientation to the Anatomic VisualizeR© environment and an introduction to the Lesson Editor tool. The virtual lessons were created as an adjunct to the lecture and independent study components of her course. The exercises were divided into an introduction and 5 lesson modules, and a problem-based approach was used for most activities. A wide range of anatomic topics and activities were included. For example, students were given an opportunity to measure the length of the virtual spinal column, construct the thoracic skeleton from component parts, identify a fracture line on an x-ray and then label the same site on the skeletal model, deconstruct the skull and locate specific bones, and visualize structures hidden deep in the abdominal cavity by making exterior structures transparent, removing extraneous structures, or by using the clipping plane tool. In October of 1998, the class of nine students took a field trip to UCSD to experience the first of two VR laboratory sessions. Their second session is scheduled for December 1998. Overall, each student will spend more than three hours of study time using Anatomic VisualizeR©. Pre- and post-tests have been developed by their teacher. These data, as well as written student comments on to the virtual learning experience, are being collected, but are not available at the time of this writing. Ten additional high school students will be given the opportunity for a similar two-day experience during February and March of 1999.

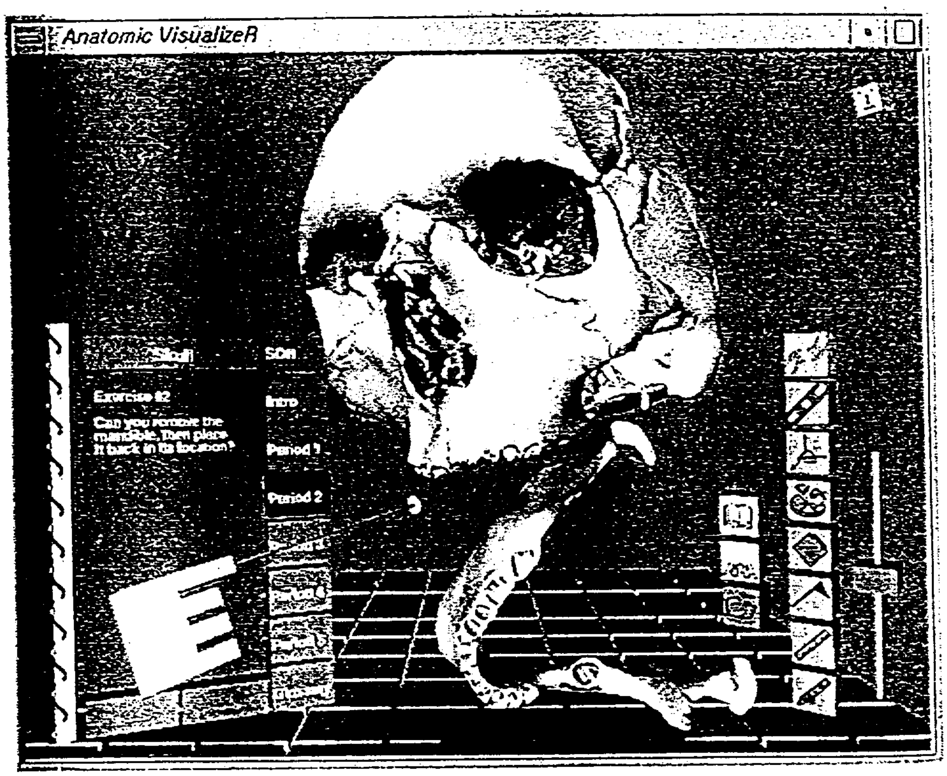

Figure 3: Anatomic VisualizeR© in the Classroom. A page from the High School Advanced Anatomy Lesson. Exercise instructions on the Study Guide page have directed the student to remove the mandible from the skull and then place it back in its location. An avatar of the student's hand appears with a pointer to aid in precise selection. Environment toolbar options appear behind (and to the left of) organ toolbar option and scale bar. Indication of anatomic position appears in the upper right hand corner.

The first Anatomic VisualizeR© lesson to be used within the UCSD School of Medicine Human Gross Anatomy course is scheduled for the final weeks of the 1998 Fall quarter. It will focus on the structure and function of the sphenoid bone shown in Figure 2 and will include an interactive demonstration by the course faculty in the lecture hall as well as opportunities for the medical students to independently study the bone and other anatomic aspects of the skull in VR.

3.3 *Future Plans*

To conclude the current phase of our activities, we will be producing a short video highlighting the developmental process, the application features, and the curricular venues in which VisualizeR is being used. The 1994 video, created at the onset of this project, has been a highly successful vehicle for communicating our initial vision. It thus seems appropriate to produce a second video at the conclusion of our DARPA-supported activities. As our current grant expires, we are also exploring a wide variety of funding options, including educational research grants and industrial partnerships. Securing ongoing support is a necessary step to fully realize the goals established more than five years ago.

Our long term plans are multifaceted. The overarching goal is for Anatomic VisualizeR© to emerge from the research laboratory and enter the classroom. To do so, lesson development must be one of our highest priority activities. Additional efforts will be expended on developing low-cost (NT or internet-based) versions of the program to ensure that the VisualizeR© environment can be used in the widest possible range of venues. As an ongoing part of all activities, we will continue to extend our understanding of human learning in virtual environments and to characterize the educational outcomes and cost-benefit of learning with these new tools.

4. Conclusions

UCSD School of Medicine has been actively exploring the use of VR to enrich anatomy education, particularly through the combination of VR and traditional curricular resources. As the period of DARPA-funded research and development comes to a close, UCSD's virtual learning environment for human anatomy has been realized. The current research activities have culminated in several pilot projects, wherein high school and medical school students have had an opportunity to participate in a brief lesson using Anatomic VisualizeR©. Data from these studies, together with a variety of anecdotal reports, strongly suggest that learning using Anatomic VisualizeR© is highly beneficial. However, a more complete curriculum must be developed, implemented, and assessed within diverse classroom contexts in order to verify the effectiveness of this VR-based instructional approach.

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Tutor, Tutorial Program, UCSD School of Medicine, 1982 - 1983.

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Education

Postdoctoral:
University of California, San Diego; Department of Medicine, Division of Pharmacology, 1980 - 1981.
Research area: Membrane biophysics

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Graduate:
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Undergraduate:
State University of New York at Buffalo; School of Nursing, 1968 - 1970 & Department of Physiology, 1970 - 1972.
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PROFESSIONAL AFFILIATIONS

- ACM (Computer Society)..
  American Medical Informatics Association.
  Association of American Medical Colleges, *Group on Educational Affairs.*
  Association of American Medical Colleges, *Group on Information Resources.*

CONTRACTS & GRANTS

PI, *Development of VisualizeR lessons for USUHS School of Nursing*, Jackson Foundation, $40,000, 1999.

PI, *VR- Multimedia Synthesis: Prototyping & System Evaluation*, (UCSD 94-6504-R), DARPA, $1,966,521, 1994-99.

PI, *3-D Perception Metrics for VE-Based Training Sys*, Office of Naval Research (UCSD 97-5263), $189,000, 1997-98.

PI, *Virtual Reality-Multimedia Synthesis* (UCSD 93-6456), Advanced Research Projects Agency, $71,600, 1993.

Co PI, *Using a Wide Area Info Server System to Deliver Medical Images over the Internet*, CERFnet, $2,5000, 1992.

Co PI, *Computer-based Instructional Programs for the Human Disease Course*, CEP, UCSD SOM, $33,000, 1991.

Co PI, *PICS: Interactive Case Studies in Pathology,* Academic Development Award, Apple Computers, $37,000, 1990.

PI, *Myocardial Sarcomere Dynamics in Treppe*, AHA (Vermont) Grant-in-Aid (awarded, funding declined), 1982.

Postdoct. Fellowship, *Sarcomere Dynamics in Cardiac Hypertrophy*, NRSA (PHS IF32HL06338), $22,000, 1982-1983.

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ARTICLE: *The Virtual Surgeon*, R. Satava, The Sciences, Journal of the New York Academy of Sciences, 11/12 1998.
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ARTICLE: *Cadaver studies move into future with virtual reality,* in La Jolla Light, March 22, 1995.
ARTICLE: *Preparing Physicians for an Ever-Changing Tomorrow,* in UCSD 's Annual Financial Report, 1994.
ARTICLE: *Training in chirurgia. Magia dell'integrazione*, in Virtual, Mensile di Realta Virtuale e Immagini di Sintesi, 1994.
TV INTERVIEW/DOCUMENTARY: *Conversations with Dr. Helene Hoffman*, UCSD Channel 35 & OLR TV, 1994.
ARTICLE: *MedPics, An Image Delivery System for Histology & Pathology*, in Int. Healthcare Newsletter, Vol 10, 1994.
MUSEUM EXHIBIT: *MedPics* in Digital Check-Up, a Visual Studies Workshop, Rochester Institute. Technology, 1993.
ARTICLE & CD ROM DEMO: *MedPics* in Multimedia Power Tools, Jerram ed, Random House/Verbum Interactive, 1993.
ARTICLE: *UCSD, a profile of a medical school using multimedia teaching* in Syllabus, Number 28, 1993.
ARTICLE: *Interactive Computer program provides a Better Path to Pathology,* in UCSD Medicine, Vol 3, 1993.

CONSULTING

Advisory Board Virtual World Magazine (The Netherlands), 1997- present.

Mitsubishi Electronic Research Laboratory, 1997.

Advisory Board of Directors, Micron Biosystems, 1994 - 1997.

Kaplan, New York, 1993 - 1996.

Merck Inc., New Jersey, 1991 - 1993.

Cardiovascular Function Lab Development Group, Oregon, 1989 - 1991.

SELECTED PRESENTATIONS

- *Academic Support Systems for Minority Medical Students,* Association of American Medical Colleges, Western Region Meeting, Asilomar CA, 3/85.

- *Developing Software Applications for Medical Education,* University of California Academic Computing Services Conference, UCLA, Los Angeles CA, 8/91.

- *PathPics: An Image Review & Tutorial Program,* Educom '91, San Diego CA, 10/91.

- *Medical Education in the 90's: Developing Network-Compatible Instructional Resources for UCSD's Core Curriculum,* Medicine Meets Virtual Reality I, San Diego CA, 6/92.

- *Computers in Clinical Education,* Faculty Development Workshop For Medical Educators, UC Office of Health Affairs, University-wide Health Sciences Committee, Oakland, CA , 10/92.

- *PathPics, An Imaged-Based Instructional Program Used in the Pathology & Histology Curriculum& Transmitted Over a Wide Area Network*, 16th Symposium on Computer Applications in Medical Care, Baltimore MD, 11/92.
- *MedPics: Innovation in Pathology Education*, Group for Research in Pathology Education, San Diego CA, 1/93.
- *MedPics,* University of California, Davis SOM Pathology Department special meeting, Davis CA, 4/93.
- *Virtual Reality/Multi-Media Synthesis: UCSD's Prototype Development Project*, Virtual Reality Systems Fall Meeting, New York City, 10/93.
- *UCSD's MedPics: Implementation & Impact on the Curriculum*, 17th Annual Symposium on Computer Applications in Medical Care, Washington DC, 11/93.
- *Virtual Reality & the Medical Curriculum: Integrating Extant & Emerging Technologies,* Medicine Meets Virtual Reality II: Interactive Technology & Healthcare Conference, San Diego CA, 1/94.
- *Providing access to tech-based learning resources in a clinical setting,* Kaiser Perm. TechGroup, SD CA, 3/94.
- *Virtual Reality & the Medical Curriculum,* CONNECT: UCSD & the Multimedia Revolution, San Diego CA, 3/94.
- *Integrating Extant & Emerging Technologies,* World Congress on Biomedical Communications, Orlando, FL, 6/94.
- *Virtual Reality & the Medical Curriculum,* Ausi VR'94, Melbourne Australia, 10/94.
- *Medical Education Meets Virtual Reality,* Medicine Meets Virtual Reality III, San Diego CA, 1/95.
- *Teaching & Technology, the Future of Medical Education,* AAMC Council of Teaching Hospitals, Seattle WA, 5/95.
- *Virtual Reality Meets Medical Education,* USC Medical Informatics Seminar, Los Angeles CA, 6/95.
- *A Virtual-Reality Multimedia System for Anatomy Training,* Medicine Meets Virtual Reality IV, San Diego CA, 1/96.
- *Teaching and Technology: A Vision for Medical Education,* AAMC Group on Business Affairs, Charleston SC, 3/96.
- *Developing a VR Multimedia System for Anatomy Training*, FASEB'96 Symposium, Washington DC, 4/96.
- *Teaching and Technology: A vision for Medical Education*, Medical Library Association Collections Group Sponsored Symposium, Kansas City MO, 6/96.
- Extending Multimedia Training into 3-D Space, Medicine 2001, Montreal Quebec, Canada, 6/96.
- *Virtual Anatomy from the Visible Man: Creating Tools for Medical Education,* Visible Human Conference, National Library of Medicine, Bethesda MD, 10/96.
- *Computers and Communications Technology in Graduate Medical Education,* Group on Resident Affairs, AAMC National Meeting, San Francisco, CA, 11/96.
- *A 3D Architecture for the Development of Virtual Anatomy Lessons,* Medicine Meets VR5, San Diego CA, 1/97.
- *Anatomic VisualizeR -- A Virtual Reality-based Application for the Study of Human Anatomy,* All University Conference on Teaching and Learning Technologies, Los Angeles, 3/97.
- *Teaching, Learning, & Information Technology -- An American Perspective.* Towards The Smart Community, Revolution'97, Adelaide Australia, 9/97.
- *Anatomic VisualizeR -Teaching & Learning Anatomy with Virtual Reality,* IEEE Workshop Chicago, 10/97.
- *Virtual Reality - Next-Generation Learning Environments,* University of San Diego, University of the Third Age, 1998 Winter session, course faculty, 1/98.
- *Assessing a VR-Based Learning Environment for anatomy Education*, Medicine Meets VR6 Conference, 1/98.
- *VR and the Medical Curriculum,* Tamkin Medical Informatics Symposium, UC Irvine, 2/98.

- *Teaching & Learning with VR,* Rice University Ctr for Tech in Teaching / Learning, 1997-98 Speaker Series, 2/98.
- *Teaching & Learning with Virtual Reality,* International Telemedical Information Society, Amsterdam, 4/98.
- *UCSD's Anatomic VisualizeR - A VR-based environment for education,* UCSD Foundation Board of Trustees Meeting, 9/98.
- *Should Computer Literacy be An Admission Criterion?* AAMC National Meeting Conference Panelist, 11/98.
- *Creating VR-based Anatomy Lessons from the Visible Human Data*, 4th International Congress on New Technology in Surgery, Munich Germany, 12/98.
- *UCSD's VisualizeR: VR for Science Education,* UCSD Connect, 12/98.
- *Anatomic VisualizeR: UCSD's Virtual Environment for Anatomy Education,* SAIC National Program Managers Meetings Week, R& D Session "Human Computer Communications" , 1/99.
- *VR-Multimedia Synthesis/ VR and Medical Education,* NASA/DARPA Project Investigator Review, 1/99.
- *Anatomic VisualizeR: Realizing the Vision of a VR-based Learning Environment,* Medicine Meets VR7, 1/99.
- *Virtual Reality for Medical Education,* NYU School of Medicine, 2/99.
- *Information Technology & Medical Education,* SUNY@Syracuse Health Sciences Center, 3/99.
- *The use of Internet resources to support a community-based core course in Primary Care*, Western Conference AAMC, Spring Faculty Development Meeting, 4/99.
- *VisualizeR*, UC Digital Media Innovation Program Workshop, UCSB, 5/99.
- *Anatomic VisualizeR*, National Association of Minority Medical Educators, San Diego, 5/99.
- *Experience with UCSD's "Anatomic VisualizeR"- A VR-based Learning Environment for Human Anatomy,* Stanford & NASA workshop on Future of Biocomputation, 6/99.
- *Anatomic VisualizeR-based Lessons on the Ear & Skull (with O. Bustos MD),* USUHS, 10/99.
- *Implementing Anatomic VisualizeR Learning Modules in Anatomy Education,* Medicine Meets VR8, 1/00

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- Hoffman, H.: *Implementing Anatomic VisualizeR Learning Modules in Anatomy Education,* Medicine Meets Virtual Reality Abstracts, 1/00.

UNPUBLISHED MATERIALS:

- Hoffman, H.: *Myocardial performance in the hypertrophied heart: Temporal relationship between the compensatory mechanisms exhibited by the isolated myocardium and the intact heart.* Doctoral dissertation, UCSD, 1980.
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- Calderon, E., Garman, K., Goltz, R., and Hoffman, H.:*The Comparison of Instructional Presentation Format on Diagnostic Skills in Dermatology.,* Poster Session, ISP Fair, 1997.
- Hoffman, H., Ramsdell, J., and Buchman, B.: *The use of Internet resources to support a community-based core course in Primary Care,.* AAMC Group on Educational Affairs, Western Region Faculty Development Conf, 1999.